THE SCALE OF THE MICROSCOPIC WORLD

KEY.

1 Hydrogen, 2 Carbon, 3 Oxygen, 4 Lithium, 5 Helium, 6 Neon, 7 Water Molecule H_2O, 8 Ethyl Chloride Molecule C_2H_5Cl, 9 Octane Molecule C_8H_{18}, 10 Glycine Molecule CH_2NH_2COOH, 11 Acetylene Molecule C_2H_2, 12 Hydrogen Chloride Molecule HCl, 13 Benzene Molecule C_6H_6, 14 Alanine Molecule CH_3CHNH_2COOH, 15 Salt Molecule NaCl, 16 Methane Molecule CH_4, 17 Halite, 18 Spirochaetes, 19 Augite, 20 Human Chromosomes, 21 Spinel, 22 Cholera Bacteria, 23 Scheelite, 24 Anthrax Bacteria, 25 Copper, 26 Pneumonia Bacteria, 27 Lazurite, 28 Diphtheria Bacteria.

Key (cont.)

29 Sulphur, 30 Typhoid Bacillus, 31 Apatite, 32 Red and White Blood Corpuscles, 33 Corundum, 34 Spirillum, 35 Pyrite, 36 Streptococci, 37 Planaria, 38 Water Flea, 39 Cyclops, 40 Zoaea, Crab Larva, 41 Liver Fluke, 42 Gnat Larva, 43 Female Rotifer, 44 Daphnia, 45 Polyclad Larva, 46 Floating Rotifer, 47 Stylonichia, 48 Stentor, 49 Radiolarian, 50 Gonyaulax, 51 Euglena, 52 Amoeba, 53 Paramoecium, 54 Vorticella, 55 Hydra, 56 Scyphistome, 57 Leptoplana.

R. C. A. TYPE
E. M. U. ELECTRON
MICROSCOPE

It is difficult to comprehend the sizes involved at the smallest end of the microscopic scale. The diameter of a hydrogen atom is about one two hundred millionth of an inch. The nucleus of the atom may be about one ten thousandth of this size. On a larger scale a rotifer is about a tenth of a millimetre across, and a male water flea may be as much as a millimetre long. There are tremendous variations in the sizes of crystals, from microscopic dimensions upwards.

The ENCYCLO
SCIENCE

CONTENTS

Illustrated PÆDIA of

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HAT SPIRAL GALAXY

IRREGULAR GALAXY

ELLIPTICAL GALAXY

SPIRAL GALAXY

HORSEHEAD NEBULA

GALAXIES AND NEBULAE

Out in space many millions of miles away there are other galaxies apart from our own. This we know by studying photographs taken through our telescopes. From them we have also been able to deduce the saucer-like shape of our own galaxy. Present observations indicate that most galaxies are smaller than our own, varying considerably in size and shape, though the majority can be classified into the types shown.

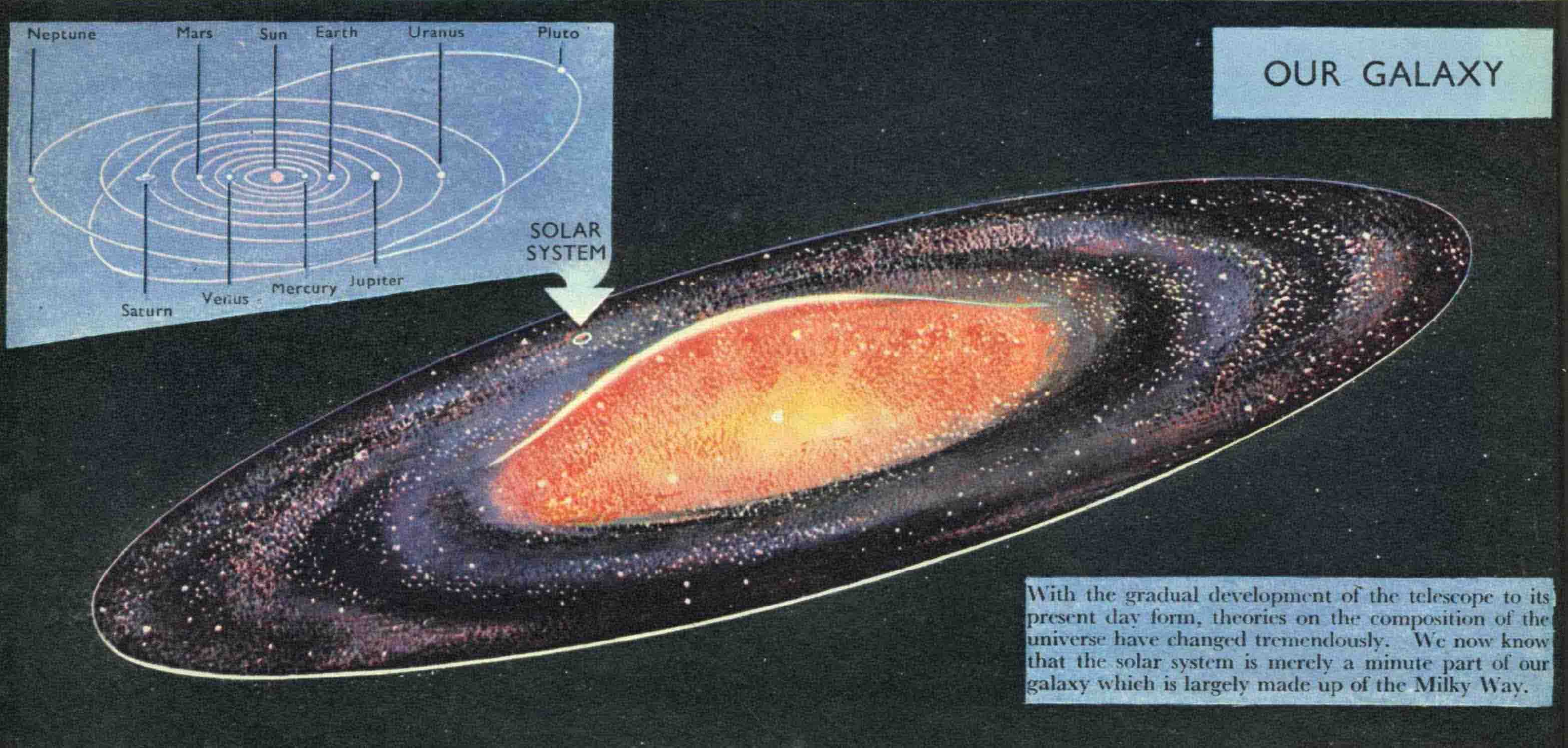
Nebulae, which occur both inside and outside our galaxy, are clouds of gas or dust of varying temperatures and may be illuminated by nearby stars.

RING NEBULA

THE SCIENTIST'S WORK

The main task of the scientist is to find out as much as he can about things in the world around us. Any useful knowledge he passes on to benefit mankind in everyday life.

The astronomer peers into space at stars in all stages of development and tries to piece together the history and future of our own galaxy. The physicist releases atomic energy to give us heat and electricity. New substances are constantly being discovered by the chemist. These discoveries have given us new medicines, fertilisers, dyes, and plastics like nylon and polythene. The raw materials may come from the air, the ground, trees or animals. The geologist aids the chemist by his constant search for oil and new minerals. The engineer helps to build dams which provide water for the irrigation of crops in dry areas, and hydro-electric power for factories. The biologist is trying to increase the amount of food we can obtain from the land by developing better varieties of plants and breeds of animals. Meanwhile our own lives are being made healthier by constant medical research. And beyond all the material gains lies the dedicated search for the universal laws which govern the existence of all things whether infinitely great or infinitely small.



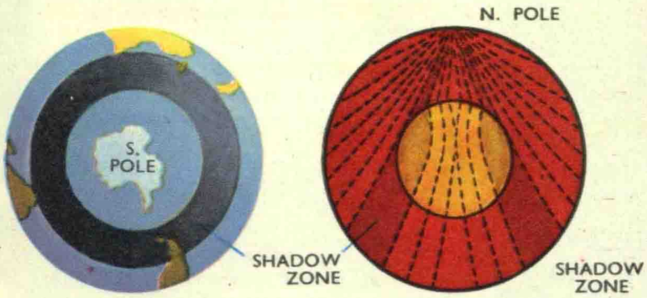
OUR GALAXY

With the gradual development of the telescope to its present day form, theories on the composition of the universe have changed tremendously. We now know that the solar system is merely a minute part of our galaxy which is largely made up of the Milky Way.

The Study of the World we live on and its Laws

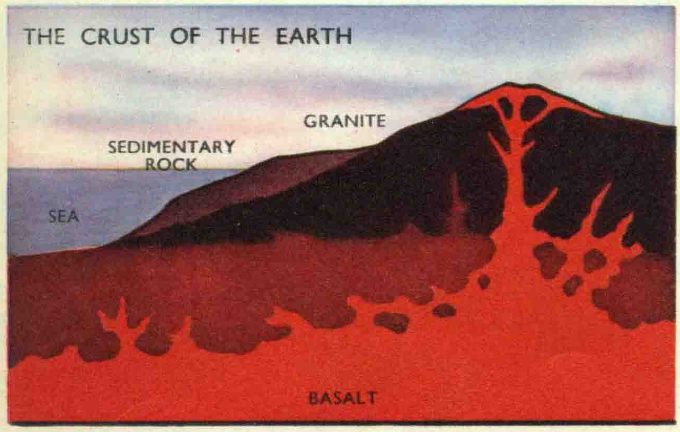
The earth is a globe rotating like a top on its axis once every 24 hours. This axis is tilted to the earth's path round the sun (a journey which takes 365 days) at an angle of $66\frac{1}{2}°$.

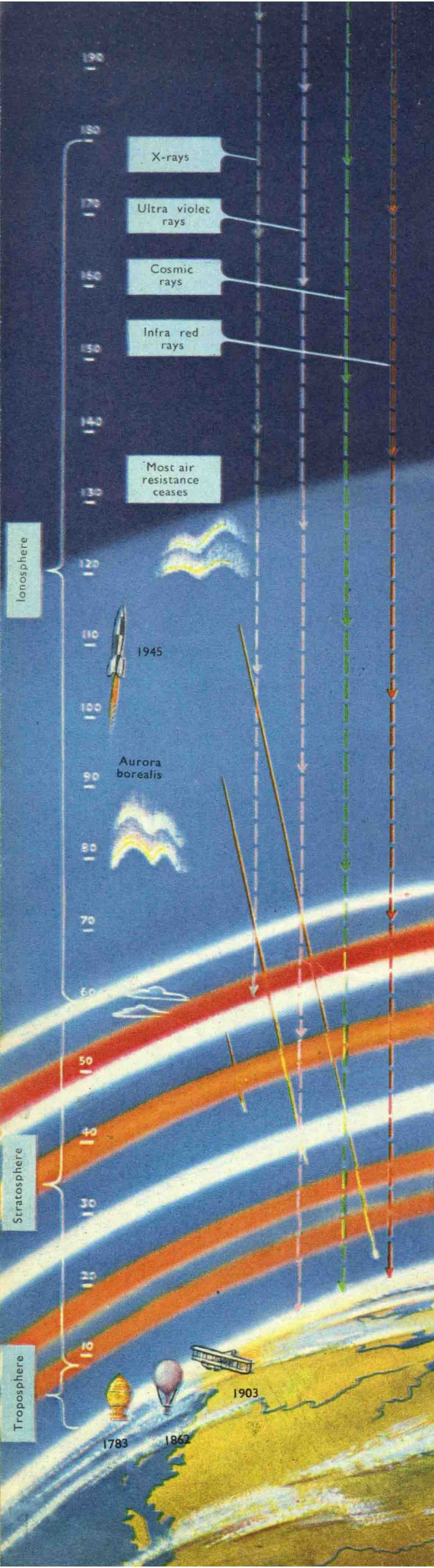
The world consists of a series of shells round an inner core. The crust and the layers immediately beneath can be largely studied from the surface rocks. These are the sedimentary rocks laid down as mud deposits over continents at one time under the sea. In some areas they have been eroded away to expose the underlying granite which forms the heart of the continents. When volcanoes erupt molten lava (basalt rock) is poured over the land. This shows that there is a layer of basalt under the granite, almost liquefied by the great pressures and heat. Below the basalt a solid layer of denser rocks gradually gives way to heavy metal oxides and a core of nickel and iron.



AN EARTHQUAKE AT THE NORTH POLE

Earthquake vibrations pass in curved waves through the earth as they are attracted towards denser material. A shadow zone is produced where waves are not received due to the big difference between waves passing through the core and those which just miss.



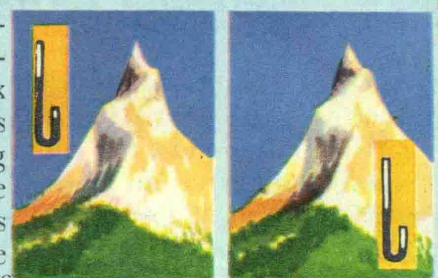


The Study of the Atmosphere

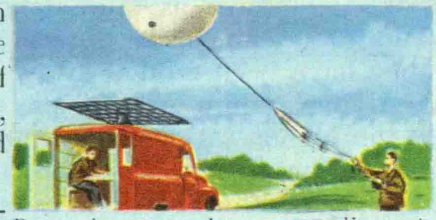
The atmosphere is a transparent envelope of gas approximately 500 miles thick surrounding the earth. It is of great importance to living things—animals breathe the oxygen it contains and plants use the carbon dioxide. The approximate composition of the atmosphere is, nitrogen, about 78 per cent., oxygen about 21 per cent., and the other 1 per cent. consists of argon, carbon dioxide, hydrogen, neon, helium and a few other gases.

The lower levels are within the reach of balloons, unmanned balloons are sent up to about 20 miles above the earth to collect scientific data, while manned balloons have yet to go so high. Rockets are now able to go far above the earth and are powerful enough to escape from the earth's gravitational pull. All these intrusions into the skies above result in much valuable information being received on atmospheric conditions. We know for example that the atmosphere is layered.

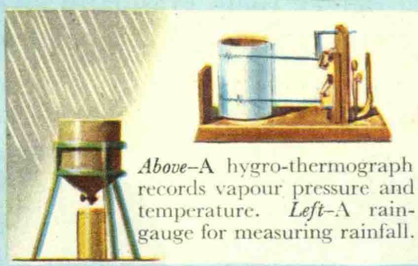
The atmosphere is important to the astronomer and the meteorologist. It not only absorbs light from the stars but also the conditions that exist there are the cause of weather.



Air is less dense (thinner) at the top of a mountain than at the bottom.

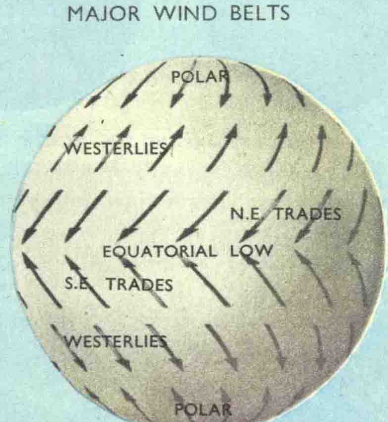


Preparing to release a radiosonde mobile weather station which will record atmospheric conditions.



Above–A hygro-thermograph records vapour pressure and temperature. *Left*–A rain-gauge for measuring rainfall.

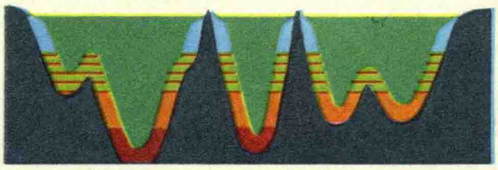
MAJOR WIND BELTS



The Study of the Sea

SEDIMENTS ON THE OCEAN FLOOR

CROSS-SECTION OF ATLANTIC OCEAN



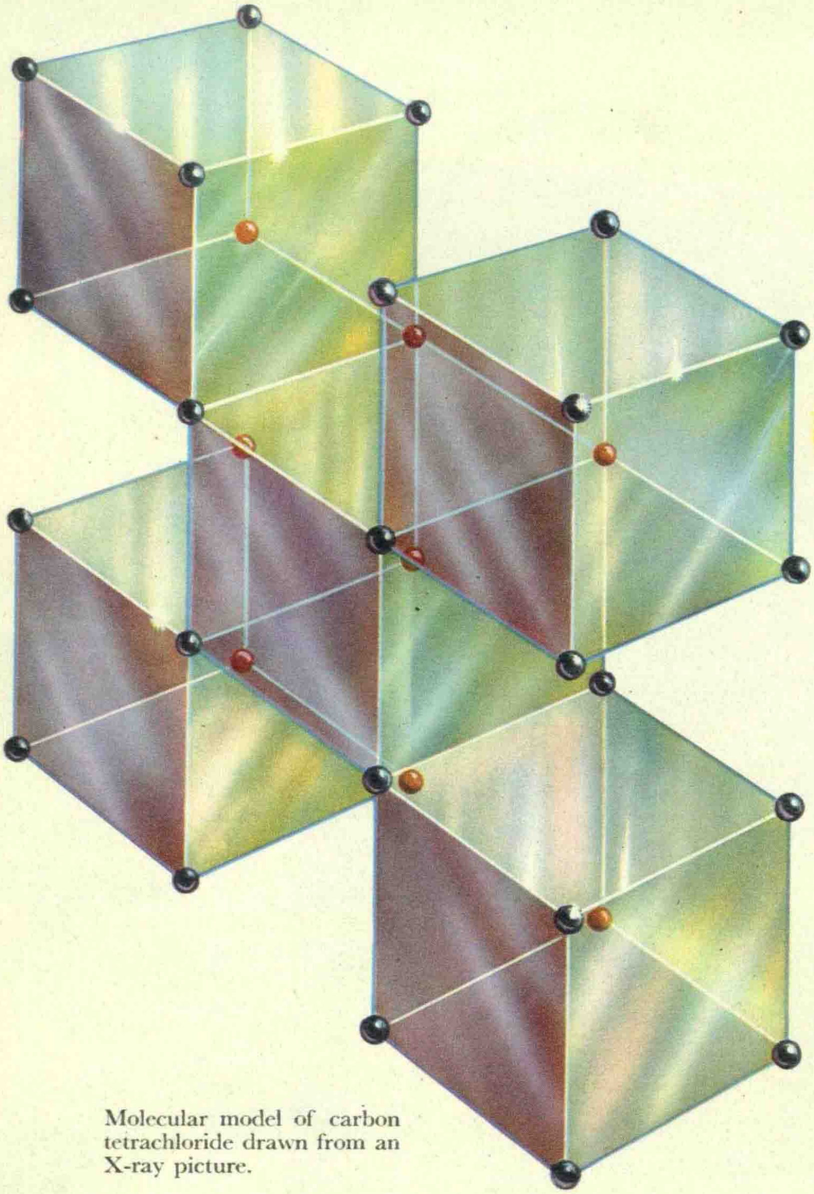
CROSS-SECTION OF PACIFIC OCEAN

Blue Clay — Oozes — Red/Green Clay — Red Clay

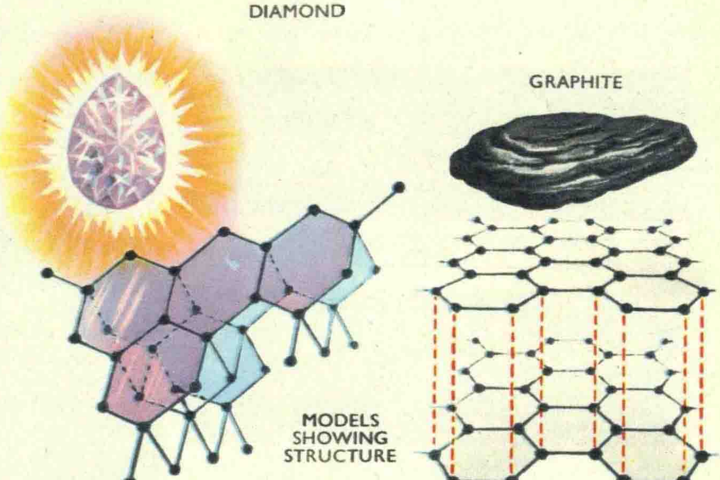
Recently, radio beams have been used to plot the sea's depth. We have learnt that the ocean bed is not flat, but there are great chasms and mountain ranges far larger and more beautifully sculptured than anything above the sea. The deepest part of the ocean is in the Marianas trench in the Pacific, a vast chasm nearly seven miles deep. The world's greatest mountain range is submerged—the Mid-Atlantic ridge. The ocean bed is the last major region of the world to be explored. Less is known about conditions there than in any other region. By dredging we know that the sediment is a red clay (cosmic and volcanic dust) containing shark's teeth.

A bathysphere is used to explore ocean depths. Its thick walls can withstand the great pressures found there.

The Nature of Materials



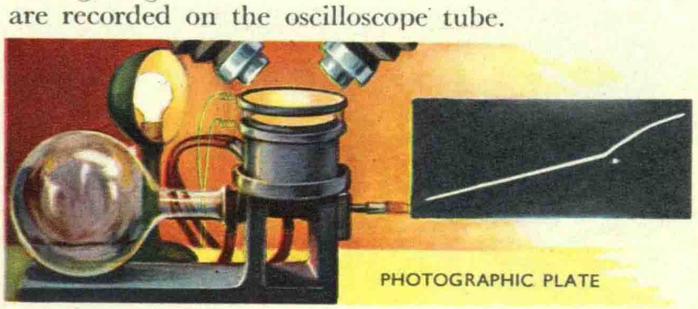
Molecular model of carbon tetrachloride drawn from an X-ray picture.



In graphite the atoms are arranged in layers which are relatively far apart so that there is a weak linkage between them. In diamond the carbon atoms are in a close-packed orderly pattern. This compact arrangement gives the crystal unique hardness.

Substances when burnt produce light which can be divided by a prism into separate bands of colour, the number and width depending on the substance.

Ultrasonic (faster than sound) vibrations are passed through a germanium transistor to detect flaws which are recorded on the oscilloscope tube.



The cloud chamber is a device for letting charged atom particles too small to see, reveal their paths as a vapour trail in the chamber which contains air and water vapour at very low pressures. The trail is photographed through the top of the chamber.

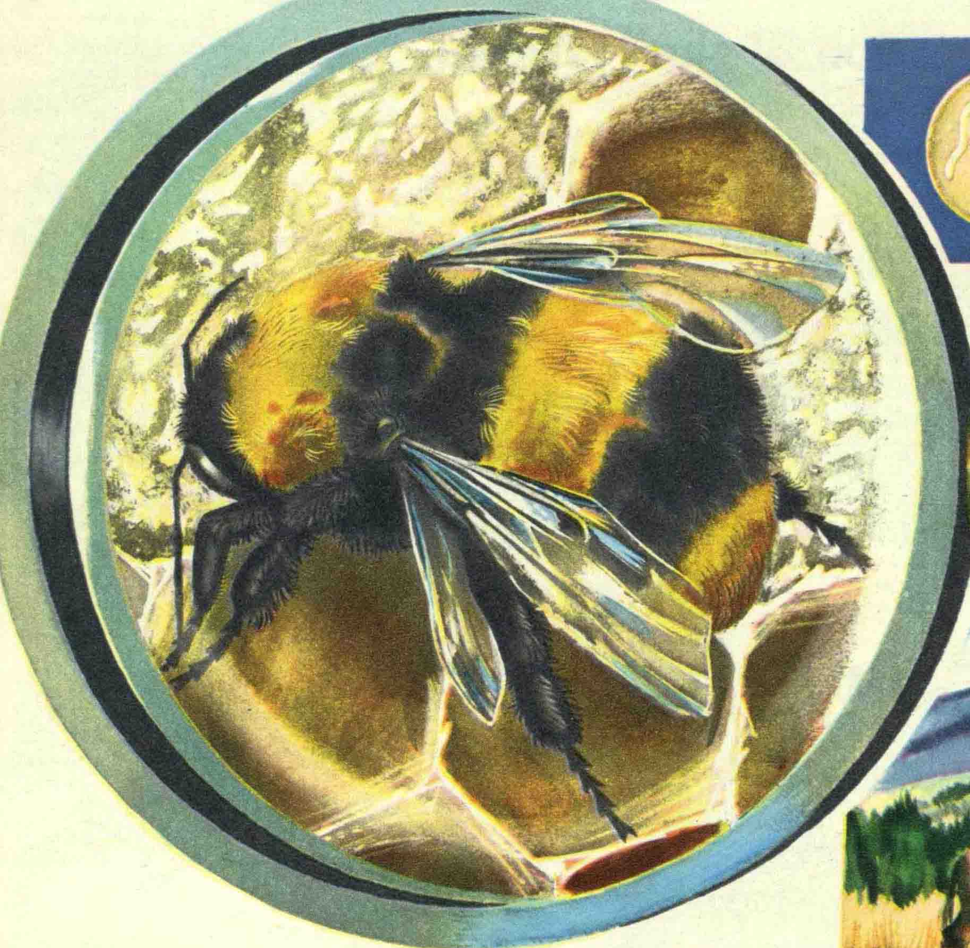
All substances are made up of basic units called atoms. There are about a hundred types of atoms. Each substance has different properties because it is made up of particular types of atoms in a certain proportion. The atmosphere around us, the ground on which we walk, the sea in which we swim—all are made up of their different atoms.

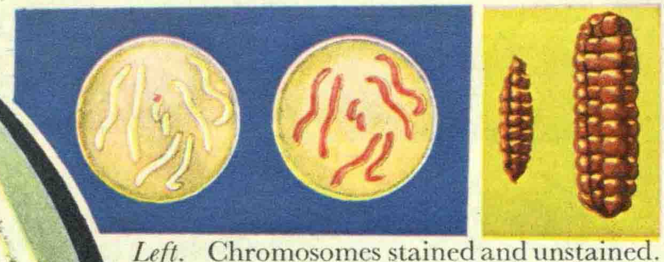
When a substance is X-rayed a pattern is obtained on the photographic plate, from which it is possible to show the relative positions of the atoms. If we were to X-ray aluminium softened by heat, a scattered pattern would be obtained indicating that the metal was soft and could be bent with less chance of breaking than a stretched piece of the same metal which shows a concentrated pattern. The properties of a substance therefore depend a great deal on the arrangement of its atoms and this explains why some things are strong, others fragile and some elastic.

Manipulation of the Material World

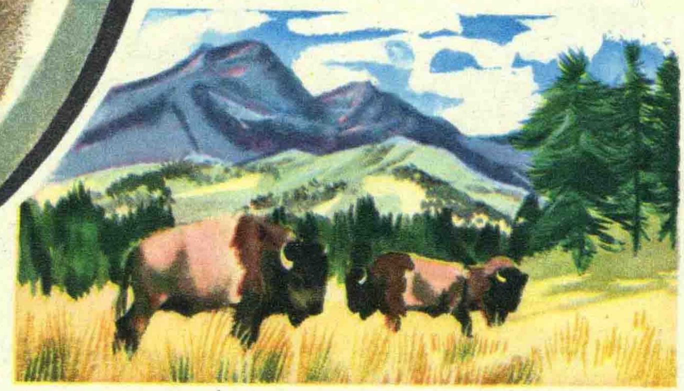
Since man first appeared on the earth he has learned to make better use of its natural resources. Water is essential for life and much of man's endeavour has been directed toward its conservation. He has re-shaped the earth's surface by digging canals, building dams, and changing the courses of rivers by moving whole mountains. The stored water can be piped direct to our homes, used to irrigate dry land, or to drive generators producing electricity.

We use raw materials such as coal for fuel, and stone for building purposes. Coal is also heated to produce coal gas. There are many by-products of this process, including coke, petroleum, oils, plastics and drugs. From many mineral ores metals are extracted. Aluminium, from bauxite, is used in aircraft construction, tin for canning food, and steel girders for building bridges. In fact, every mineral on the earth's surface has some use, as have most of the waste products formed during their refining.





Left. Chromosomes stained and unstained. A study of these has shown them to carry the hereditary characters. Better plants result. *Right.* Wild and cultivated maize.



American National Parks are founded to preserve the life of wild animals such as bison.

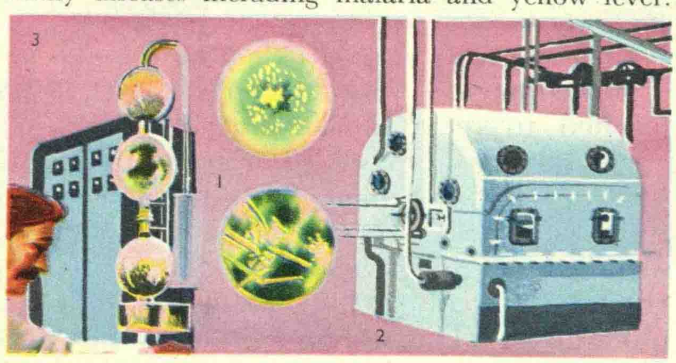
The Nature of Life

No-one knows what life is. We are able to compare living things with non-living things and to note the difference between them, but what it is that makes one thing living and another non-living is still a mystery.

All living things are composed of a fundamental material, protoplasm. This is contained within a " wall " (cell membrane) and the unit is termed a cell. This is the basic unit of life in the same way that the atom is the basic unit of matter. The smallest living thing is one-celled, whereas we are made up of millions of cells.

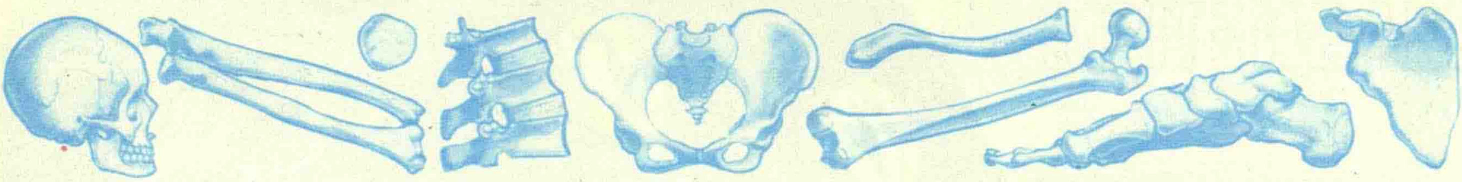
We can control life in many ways to our advantage. We use chemicals to destroy harmful organisms in swamps, as drugs to protect us against disease, and as fertilisers to grow more crops. Cultivated crops have been bred from wild plants, and animals bred to yield more meat and milk, and better quality skins. Man's interference with nature has not always produced the desired result. The rabbits introduced into Australia became pests. Man learns by his failures, though, and in this way progress is made.

Spraying has played a major part in the control of many diseases including malaria and yellow fever.



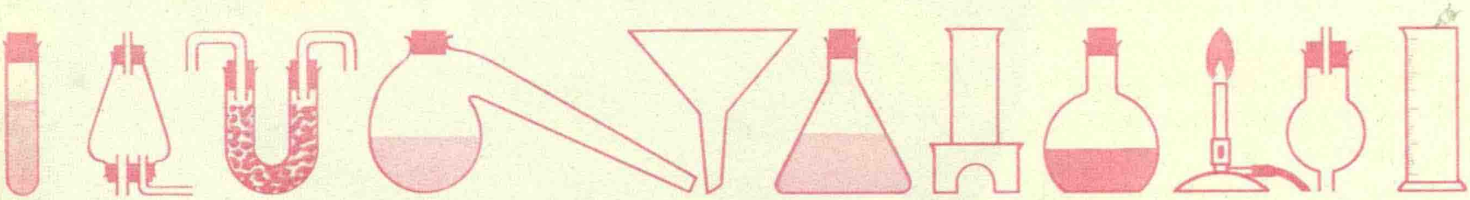
1. *Above.* Germ culture on jelly contaminated by a mould produces penicillin. *Below.* Part of the culture highly magnified. 2. Sterile cultures grow rapidly in tanks. 3. Separation of pure penicillin.

THE SCIENCES



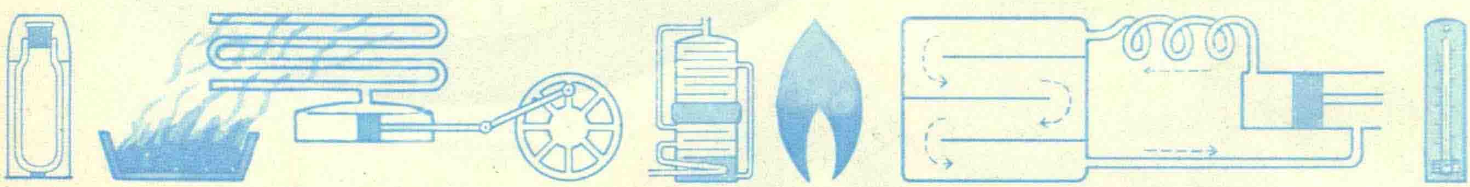
Agriculture
Anatomy
Archaeology

Astronomy
Bacteriology
Biology



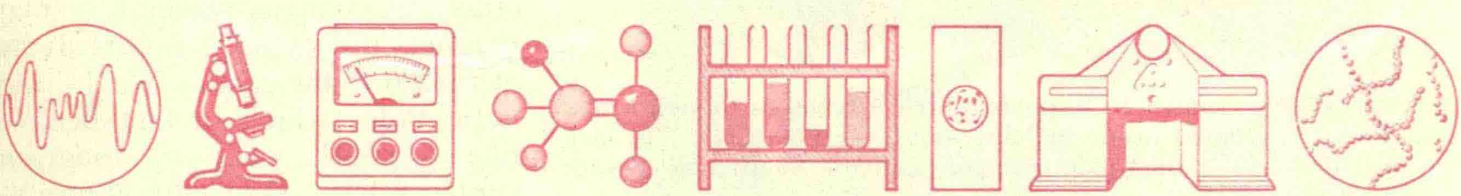
Chemistry
Colour Physics
Density Physics

Electricity
Electronics
Fuel Technology



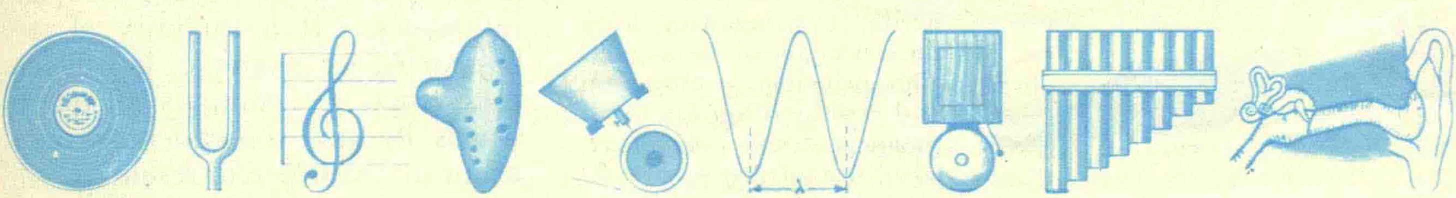
Geology
Heat Physics
Light

Magnetic Physics
Mechanics
Metallurgy



Meteorology
Navigation
Nuclear Physics

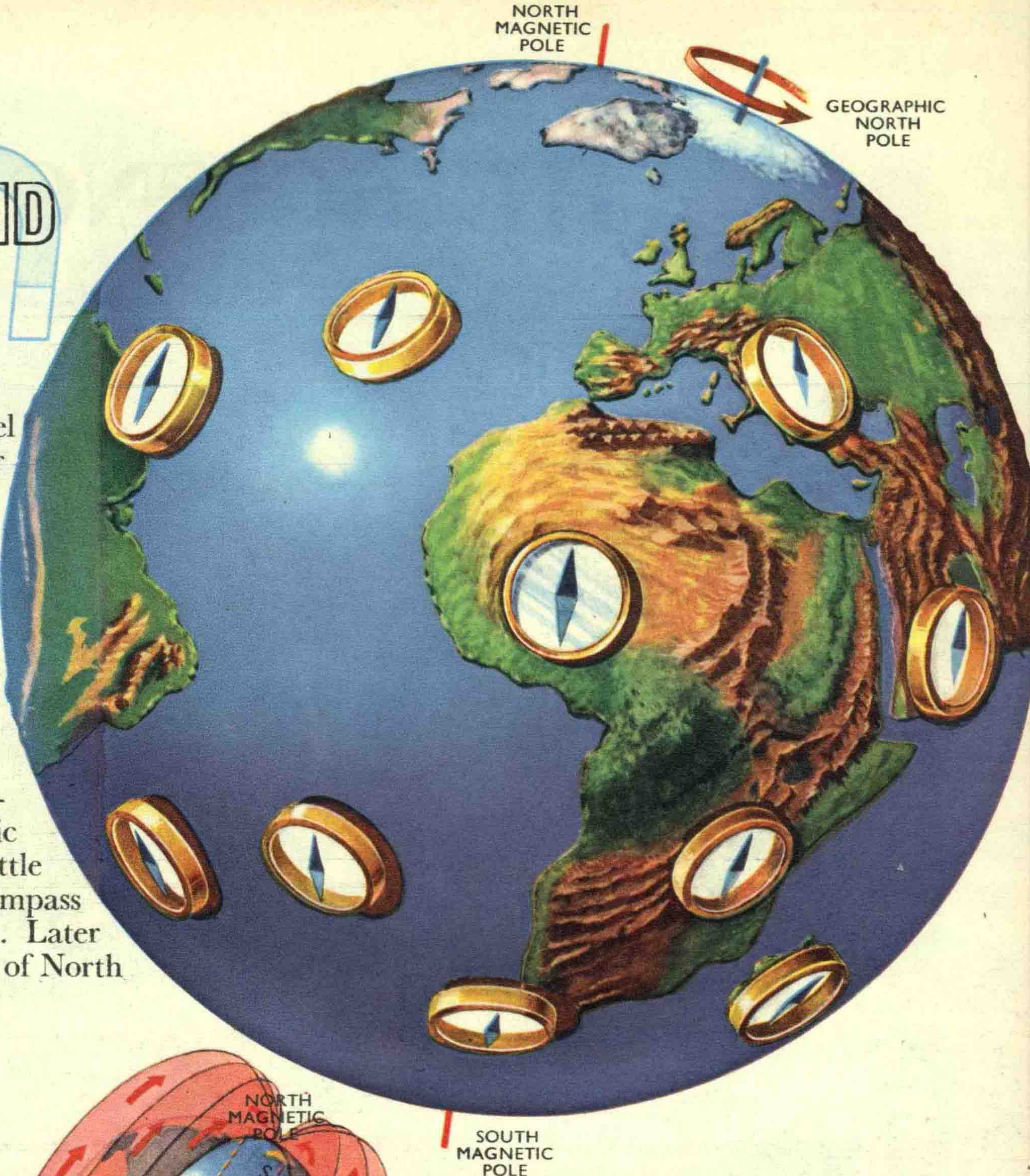
Palaeontology
Physiology
Sound

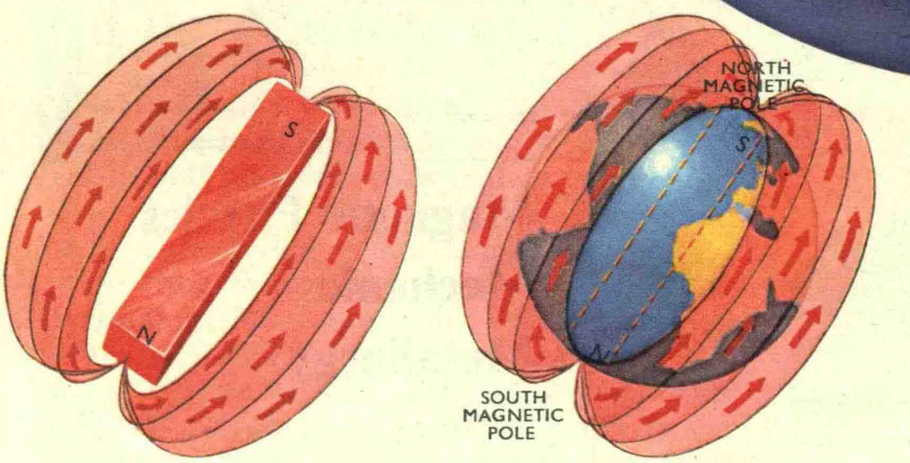


MAGNETS AND MAGNETISM

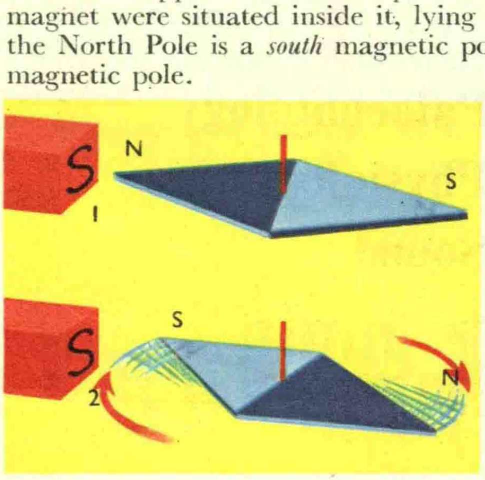
A magnet may be iron or steel or lodestone, and has the power to attract to it other pieces of iron. This force of attraction is called magnetism. The largest magnet of all is the earth.

North by the compass needle is very seldom found to be true geographical north. In England, it is about 9° West of North. Another interesting point is that magnetic north is gradually changing a little less North each year. The compass pointed due North last in 1657. Later it shifted gradually to 14° west of North (1800).





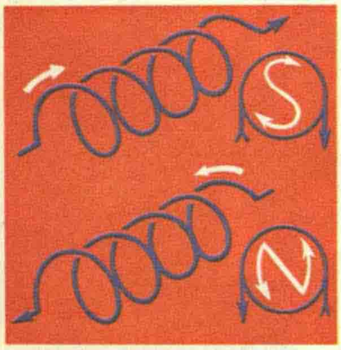
The earth approximates to a sphere which behaves as though a bar magnet were situated inside it, lying along the Polar axis. In fact the North Pole is a *south* magnetic pole and the South Pole a *north* magnetic pole.



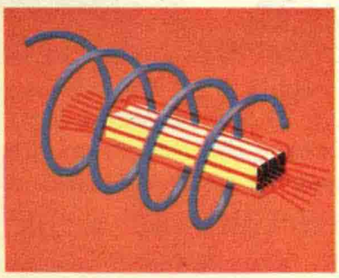
A compass needle is suspended near the south pole of a magnet. The north pole of the compass needle (1) is attracted to the south pole of the magnet, and points to it. The south pole of the needle (2) swings away from the south pole of the magnet. This principle of attraction and repulsion applies to all magnets. *Unlike poles attract, whilst like poles repel.*

Every magnet has two poles, north and south, one at each end. If two magnets are suspended near each other so that they can swing freely, the north pole of one will be attracted to the south pole of the other. A compass needle is a small magnet, and its north pole is always attracted to the earth's North Magnetic Pole (which in fact behaves like a south pole—*see* diagrams centre left). With an allowance made for the Magnetic Variation, the direction of True North can easily be obtained. In taking a compass reading, however, precautions must be taken to avoid interference from outside magnetic influences. If a quantity of steel is nearby, for example, it will tend to attract the compass needle towards it, and consequently an inaccurate reading will result.

A pattern of magnetised iron filings, showing the magnetic field of force around an electric wire.



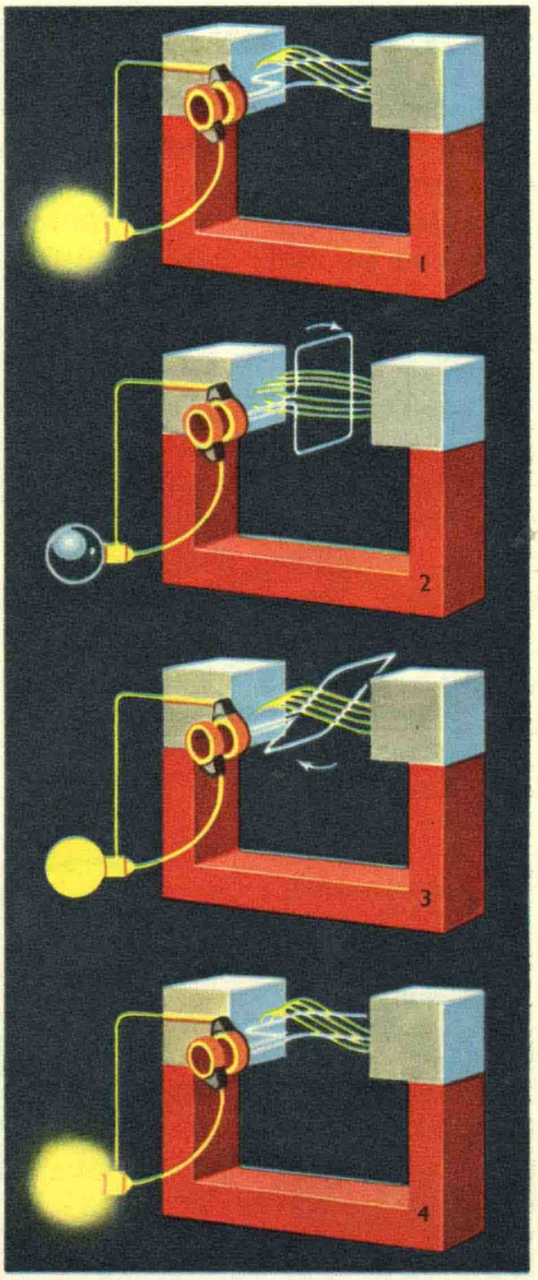
Looking from one end an electric current moves clockwise. The magnetic pole at that end will be south.

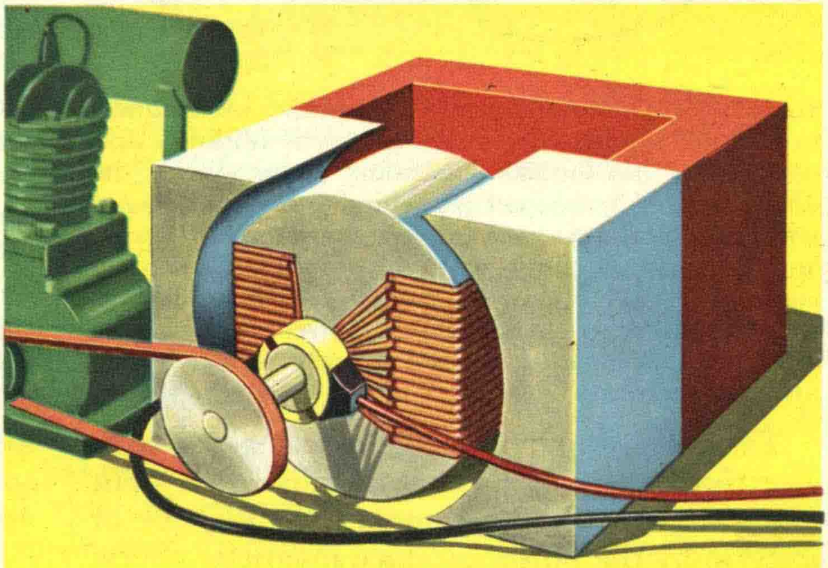


A magnet moving inside a coil produces an electric current.

The chief metals that can be magnetised *permanently* are iron, steel, nickel, and cobalt. When, however, an electric current is passed through a coil of copper wire a *temporary* magnetic field is set up around it, similar to the permanent effect of a bar magnet. It has both north and south poles. This principle is used in making simple electric motors.

When a bar magnet is moved into a coil of copper wire, an electric current is set up in the coil, even though it is not connected to any source of power. The most important use of this idea is in the electric generator. In the simplified diagram (top right) the sequence of generating the current is shown. In fig. 1 many lines of magnetic force are being cut as the coil turns, and a lamp wired into the circuit lights and shows that a current is passing through it. In fig. 2 no lines of force are being cut, for the coil is moving along them, and so the lamp goes out. Fig. 3 shows the coil starting to cut a few of the lines of force; the current is small but increasing. The coil, however, has turned over. This makes the current reverse its direction. In fig. 4 the coil is cutting many lines of force again, so the current flow is strong. Since the coil is still upside-down the current still flows in the opposite direction from before. Thus half the time the current flows one way, half the other way. This is called an *alternating current* (A.C.). Most of our homes use alternating current rather than the single direction *direct current* (D.C.) as produced by a battery. It has been found that alternating current has several advantages which make it more suitable for domestic use. It is much easier to change the voltage of an alternating current by using a transformer, so that electricity can be transmitted along cables across the countryside at high voltages, which can be lowered when the power is needed for use in our homes. On the other hand D.C. is commonly used where submarine cables are in operation.



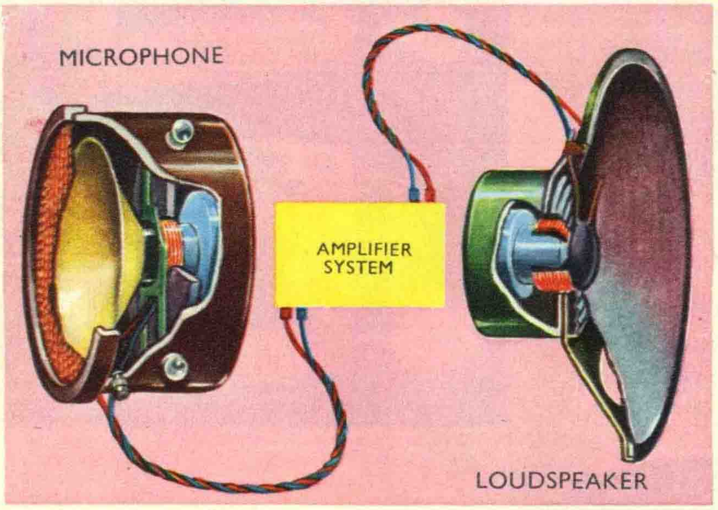


A simple power-driven direct current generator. In the centre of the magnet the coils rotate and cut the lines of force. Carbon brushes conduct the current from the coil. Full scale generators are much more complicated.

The Uses of Magnets

Today hundreds of kinds of magnets are used in science and industry. Electro-magnets are used more widely than permanent ones because they can be made more powerful, and they can be more easily controlled. Some of the most interesting uses of electro-magnets are in cathode-ray tubes, cyclotrons (in nuclear engineering) and in electronic equipment. Magnets are used to guide beams of electric charges along a certain path, in much the same way as lenses do with light.

Geologists seeking oil-bearing rocks sometimes employ a magnetometer, which can "explore" the rock strata by measuring the relative magnetic pull of the rocks in the Earth's surface. Electric bells have electro-magnets which intermittently move the hammer backwards and forwards, striking it against the gong.



Some types of microphone and loudspeaker use magnets to convert sound waves into electrical impulses and back again into sound. The sound waves vibrate the diaphragm. The magnet set behind it is wound round with wire. As the distance between the metal diaphragm and the magnet alters with the vibration, electrical currents are set up in the wires. The currents pass to an amplifier, where the signal is strengthened. The amplifier is connected to the loudspeaker, which may also incorporate a magnet.

Telegraphy and repeater clocks work with electro-magnets. Electrical pulses are sent along wires to the instruments. In the case of telegraphy the pulses produce magnetic effects which select the letters to be reproduced as words in a telegram. With repeater clocks pulses are sent each minute from a master clock. These impulses set up magnetic effects

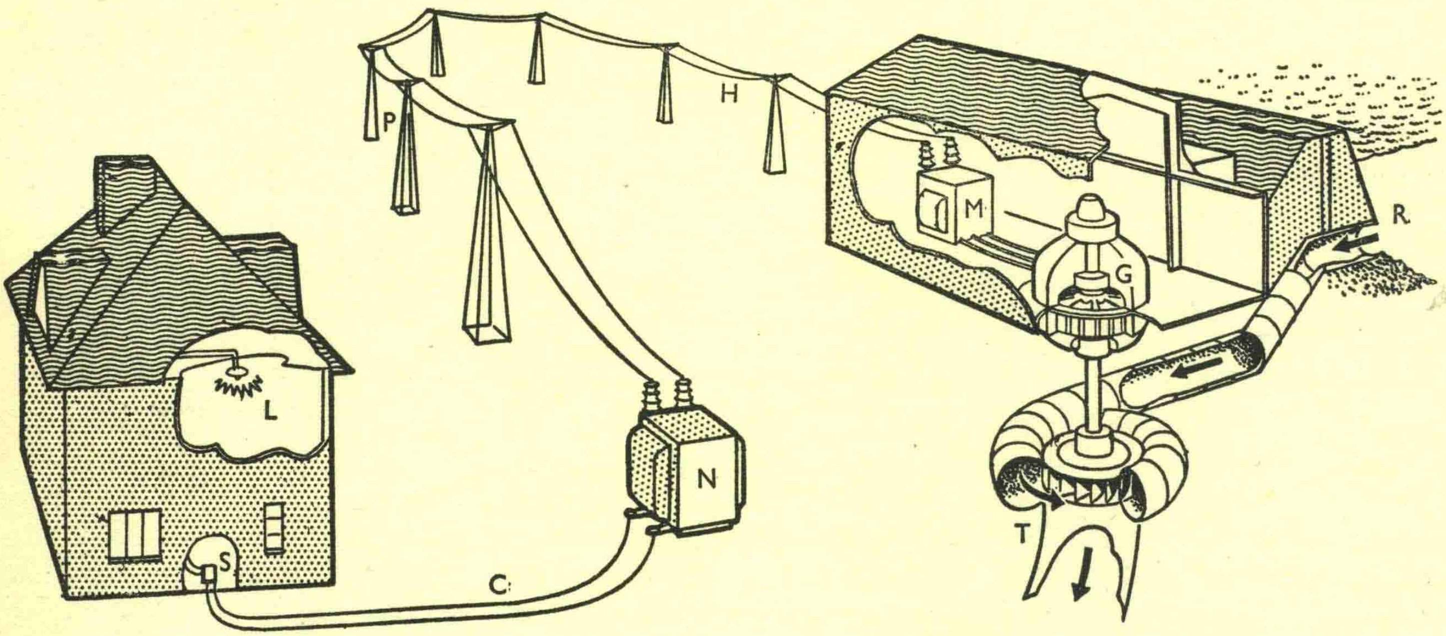
Electro-magnets provide a useful way of transporting scrap iron from place to place in the breaker's yard. Suspended from the arm of a crane the electro-magnet can be switched on when the scrap needs to be lifted, hoisted high with its load for travelling, and switched off for dumping.

in the repeater clocks, so that their hands move in time with those of the master clock.

The refuse disposal departments of city corporations and county councils use magnets for a very different purpose. When they are dealing with rubbish that contains valuable metal fragments, they employ magnetic separators which pull out the metal as it goes over a conveyor belt. In scrap yards breaking of scrap iron is sometimes carried out by smashing it with a heavy steel ball, dropped from a great height. The ball falls from a powerful electro-magnet, which picks it up again after it has done its work.

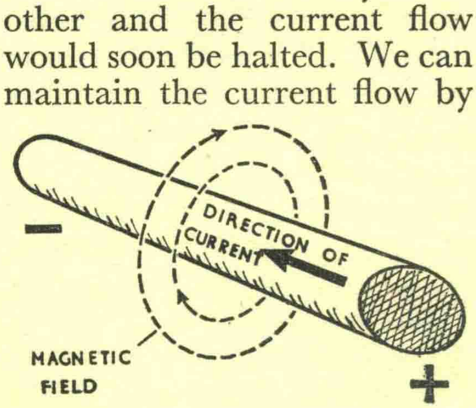
The two World Wars have brought new uses for magnets into being. Amongst the more spectacular of these are the limpet mines, attached to ships below the waterline by "frogmen", swimmers equipped to remain below the surface for long periods. The limpet mines incorporate a magnet which holds the mine (later to be detonated by a time fuse) to the steel hull of the ship.

THE SCIENCE OF ELECTRICAL PHYSICS

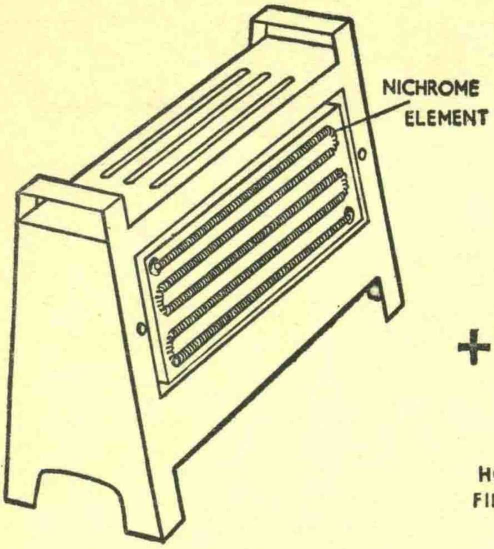


The energy of the reservoir (R) is used to supply our needs such as heat and light (L). Water rushing downhill drives the turbine (T) connected to the generator (G) producing electricity, but the voltage has to be stepped up by the transformer (M) before it is sent out along the high tension cables (H) carried on the familiar pylons (P). The voltage is stepped down by the transformer (N) and the current reaches the consumer's meter (S) through the local system (C) at 240 V.

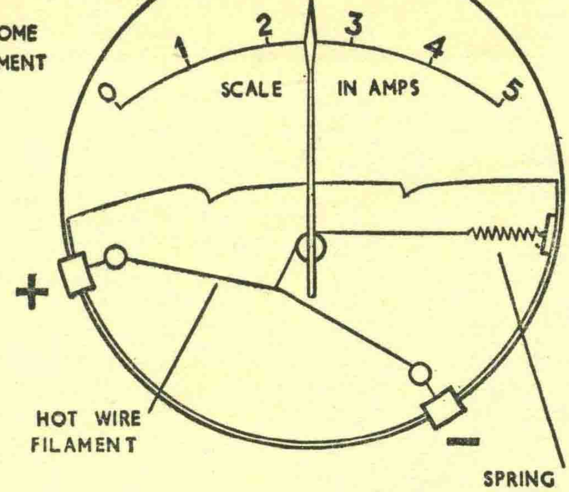
All matter is composed of atoms, those tiny particles that can be subdivided into a small central core, the nucleus, and a surrounding cloud of electrons. The atom is so small that it is invisible to even the most powerful of microscopes, but the force of attraction existing between the nucleus and the electrons is tremendous. In order that the electrons can withstand this force of attraction towards the nucleus they must move at great speed around the nucleus—in much the same way that a marble must move at speed around the edge of a saucer to prevent it falling into the middle under the attraction of gravity. Early experimenters assigned charges to these particles: the electrons were said to be negatively charged and the nucleus positively charged. In solid matter the nuclei form a rigid symmetrical structure with the vast space between atoms filled by the minute mobile electrons. A positive charge placed at the face of this structure can move electrons from atom to atom so that there is a movement of electrons, although at any particular point the atom remains electrically neutral. If the electrons are moved easily among the atoms, then the substance is said to be a good conductor of electricity; examples are silver, copper, and most other metals. In other substances it may be necessary to apply a very great charge to produce a very small flow of electrons and these substances are called insulators or non-conductors. Thus electricity is the flow of charged particles (electrons). Usually copper wire (on account of its durability and cheapness) is used as the conductor in electrical devices and for the transmission of electricity; copper wires of only 1/20th inch diameter are capable of carrying enough electric current to heat an electric fire. If, by means of a positive charge, we cause electrons to move along a copper wire we should soon have a surplus at one end and a deficiency at the other and the current flow would soon be halted. We can maintain the current flow by



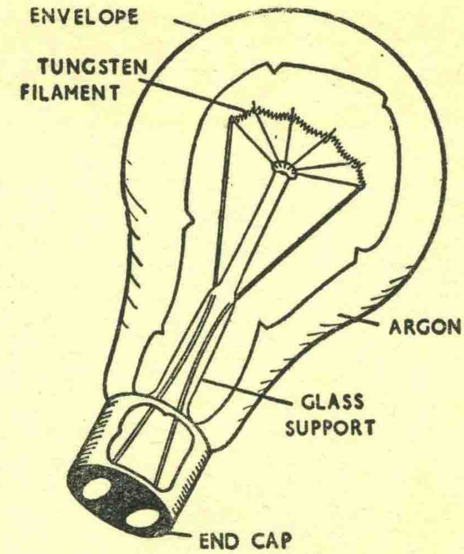
The lines of force around a current-carrying conductor.



A familiar example of the heating effect of a current.



The hot-wire ammeter can measure alternating currents.



The heated tungsten filament emits white light.

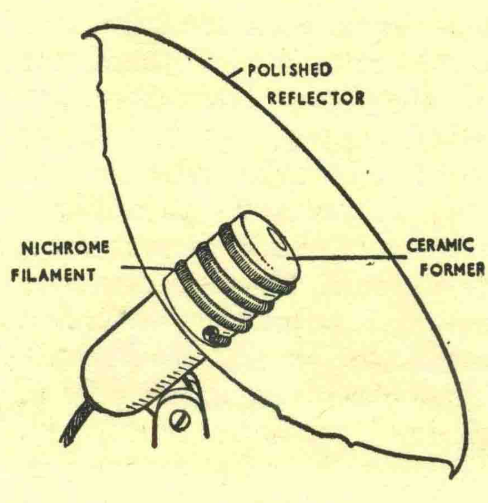
using the surplus to supplement the deficiency and this can be done by completing the circuit with another conductor.

One means of promoting an electric current flow is the battery; this is a chemical device, which has two terminals—a positive terminal deficient in electrons and a negative terminal which has an excess of electrons. If a copper wire is connected between the terminals there occurs a steady flow of electrons in the wire from the negative electrode to the positive electrode and this flow continues until the battery is exhausted. Even in copper wire there is a resistance to the passage of the electrons and on account of this the wire becomes warm owing to the release of heat. By using materials such as nichrome (in electric fires) and tungsten (in electric lamps) in the form of thin wires it is possible to make use of this heating effect; in addition, such metals resist the movement of their electrons and so develop greater heat.

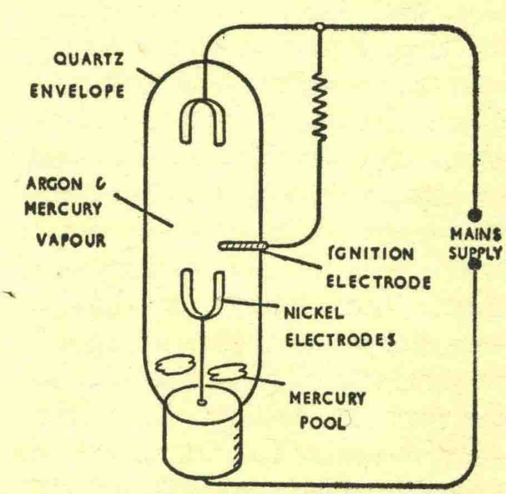
One of the instruments used by engineers to measure electric current depends on the heating effect and it is commonly called a hot-wire ammeter. A pointer mounted on a pivot is controlled by a spring and a wire that carries the current to be measured. As the wire heats and expands it allows the spring to contract and move the pointer over the scale.

Certain materials when heated emit radiation which can be used for many purposes.

A common type of infra-red radiator. The heat rays are invisible; the nichrome is seen to glow because red light is also emitted.

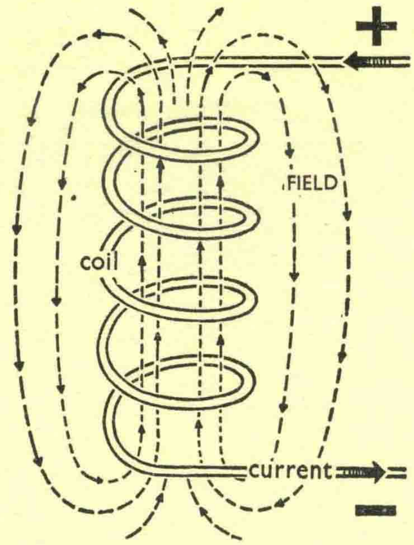


Nichrome heated to red heat gives strong emission of infra-red rays. These are used for drying purposes; softening of plastics for moulding purposes; baking and grilling of food; and in the treatment of skin diseases. Mercury vapour when ionised in an electronic arc emits ultra-violet radiation. This is used in radiation therapy, as a wavelength standard in spectrographic laboratories and for lighting purposes. Ultra-violet rays give sun-tan.

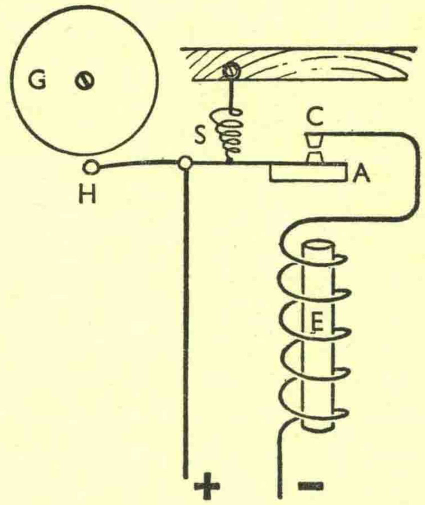


A mercury vapour lamp. The ignition electrode in only used to start the discharge by vaporising the pool of mercury.

Electric Current and the Magnetic Effect



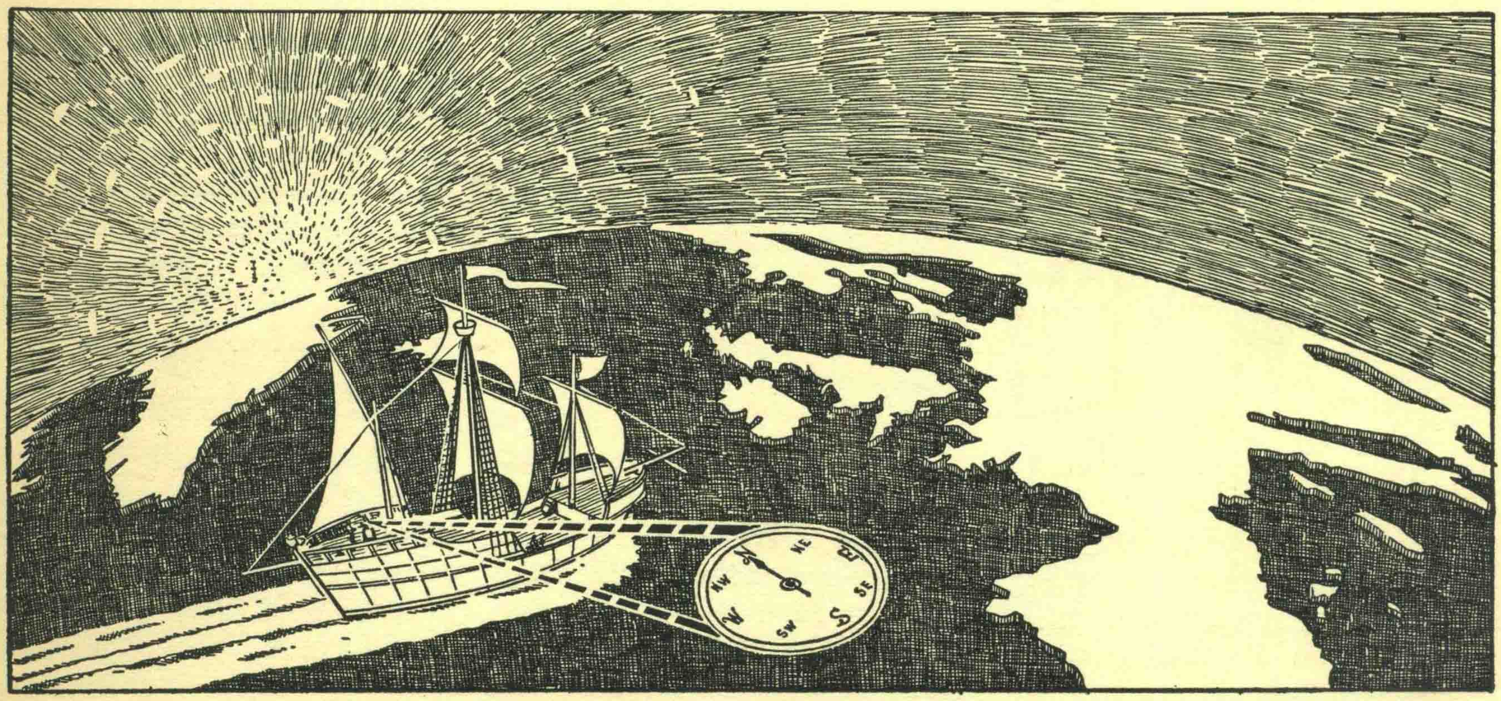
Here the lines of force are similar to those around a bar-magnet.



Electric bell: A = armature, C = contacts, E = electromagnet, G = gong, H = striker, S = spring.

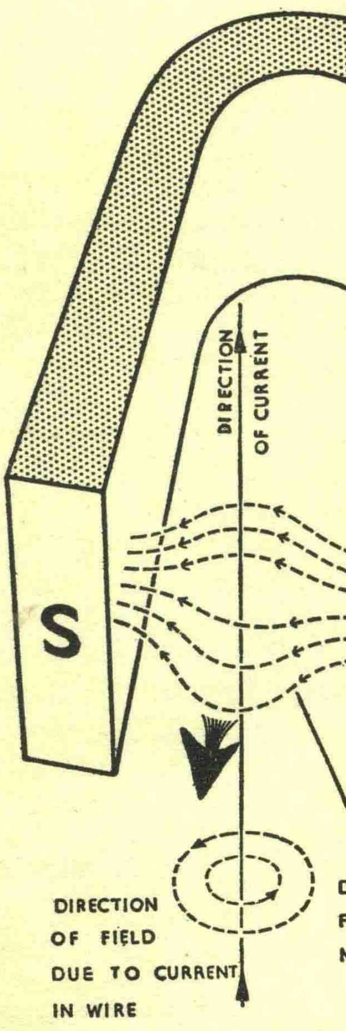
In order to make electricity operate machines such as lifts, electric trucks, and lathes, we use an electric motor; and here we have a very important application of the relationship between electricity and magnetism. Most of us are familiar with magnets—those pieces of iron (usually in an alloy with nickel and cobalt) possessing the remarkable power of attracting other pieces of iron that are in their magnetic field. Equally remarkable is the fact that a wire that is carrying an electric current is surrounded by a magnetic field. Magnetic fields are pictured as consisting of lines of force and the diagram shows the field around a wire. A compass needle, which is a freely suspended magnet, when placed in a magnetic field will align itself with the lines of force. Not surprisingly the strength of the field increases as the current is increased; but rather than use very large currents to produce strong fields it is possible to pass a small current through a long piece of wire wound into a coil. The coil then behaves exactly like a bar magnet but we can easily change its attractive force by adjusting the flow of electric current. Also the strength of the magnet produced in this way can be much increased by the insertion of a piece of soft iron into the coil.

There are many applications of very simple electromagnets as they are called, such as in the relay where by passing a current through a coil and so producing a magnet we can attract a piece of iron, called the armature, and arrange that it operate an electric switch. Another familiar device is the electric bell in which an armature, having a striker attached to it, is attracted by an electromagnet. The arrangement is such that the circuit through the coil is broken just as the armature reaches the magnet. The armature is then pulled back by a spring attached to it and the action repeats indefinitely.



The Motor Principle

We are all familiar with the forces of attraction and repulsion between two magnets and so it is not surprising to learn that similar forces exist between a magnet produced by passing an electric current through a copper wire and an ordinary magnet. A simple demonstration may be given by arranging a copper wire to hang freely between the poles of an ordinary horseshoe magnet, when of course the wire is quite unaffected by the presence of the magnet. If now a current be passed through the wire as shown in the diagram, then the wire will move in the direction indicated. Reversal of either the direction of the current or of the position of the magnet poles (but not of both) results in the wire moving in the opposite direction. We next see how this type of interaction can be used to provide continuous rotary motion. The principle of doing this may be shown by arranging a loop of wire in a magnetic field as in the diagram; and then if we pass a current through the loop we find that it moves until its plane is perpendicular to the lines of force of the magnetic field, and having reached this position it shows no further tendency to move or rotate. If, however, we can reverse the direction of the current in the coil just at the moment when it arrives at its limiting position, then it will continue to rotate so that it may take up a new position corresponding to the coil having turned through 180°. An automatic switch that will reverse the direction of the current at the right moments is called a commutator and its use enables us to produce an electric motor that will continue to rotate indefinitely.

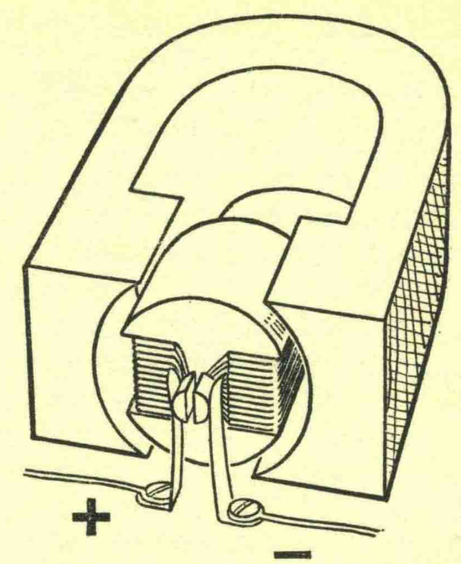


The broad arrow shows the direction of the force that acts on a current flowing in a magnetic field.

Large electric motors normally have armatures, as the moving parts of electric machines are called, with many coils wound on an iron former or framework; the stationary magnets, which are said to form the field, are usually of the electromagnetic variety.

Meters

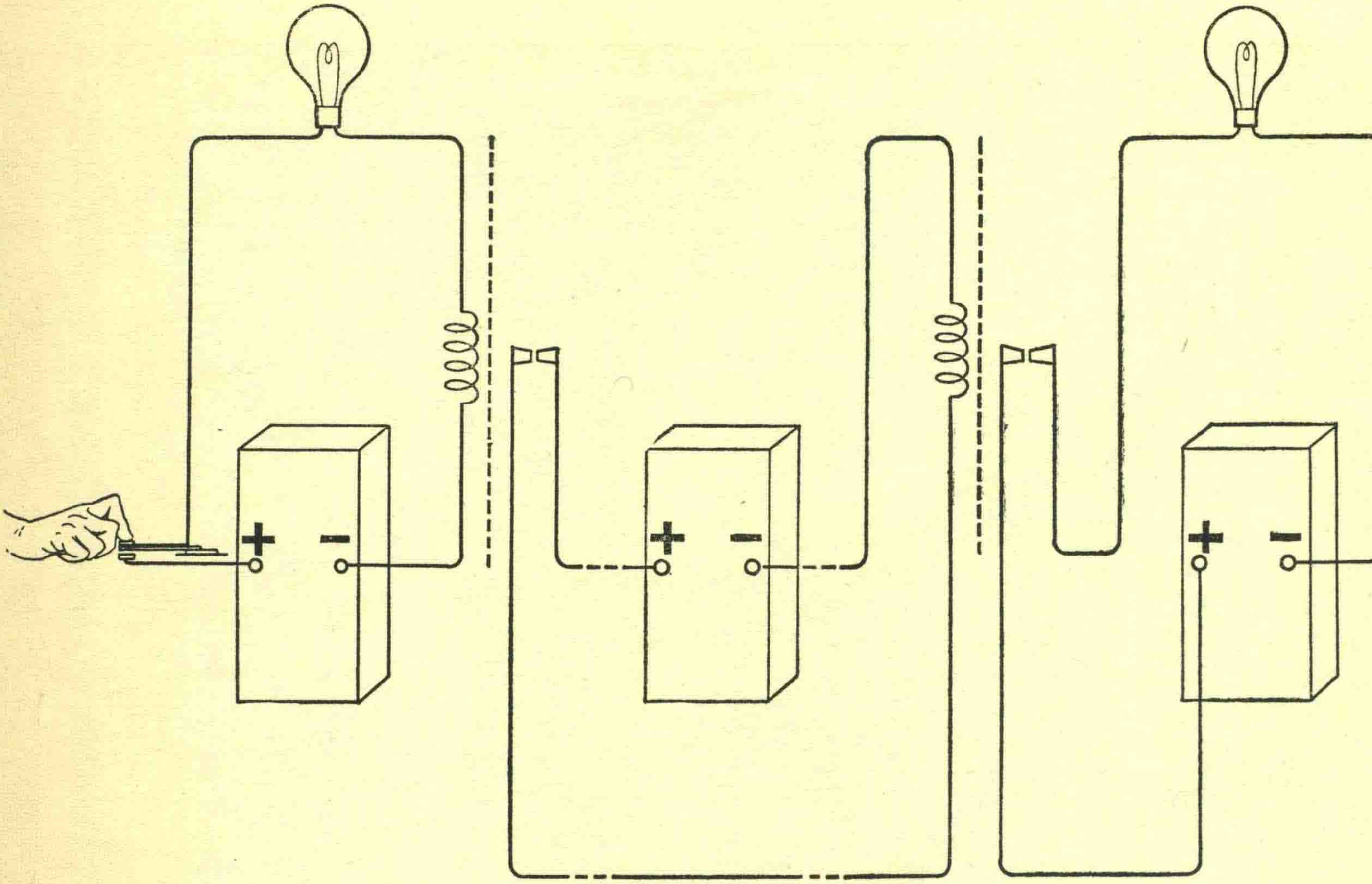
A very important application of the motor principle, as outlined above, is met with in moving-coil meters, which are used in high-class measuring instruments on account of their great accuracy. They consist essentially of a coil of wire wound on a light former mounted between the poles of a powerful permanent magnet. As in the motor, the passage of current through the coil results in its rotation, but it is now resisted by a pair of springs in such a way that the rotation is proportional to the current. Thus by attaching a light pointer, which moves over a calibrated scale, it is possible to measure currents. By making the device very sensitive, so that the coil rotates through a large angle when a small current flows, then we can conveniently place a large resistance in series with it and measure voltages. In the latter application a meter with a full-scale deflection of one milliamp or less is normally to be preferred.



A coil of wire carrying a current in a magnetic field tends to rotate.

The Telegraph and the Telephone

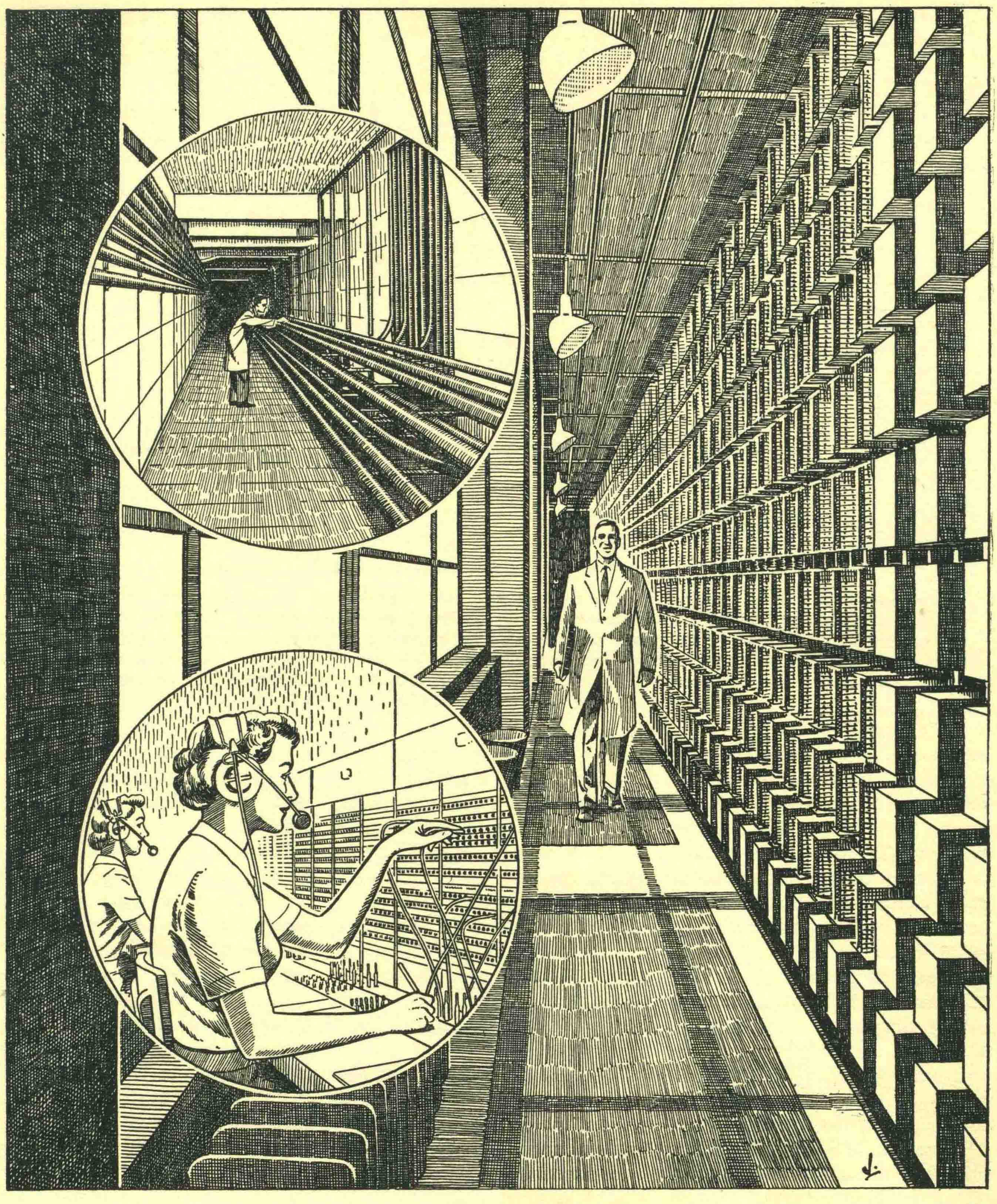
One of the early applications of electricity was that of communication over a distance. Basically all that is necessary is that the sender shall be provided with a switch to complete a circuit contain-



The telegraph provides a means of sending Morse Code messages over long distances. The circuit above is divided into three parts: the transmitter on the left, the receiver on the right, and the connecting wires represented by the central section. Each stage has its own battery to make up the loss of power due to the resistance of the wires. Pressing the key completes the transmitter circuit and closes the contacts of the first relay switch. This completes the central circuit which in turn activates the second relay. As the contacts of the second relay close, a current flows through the lamp.

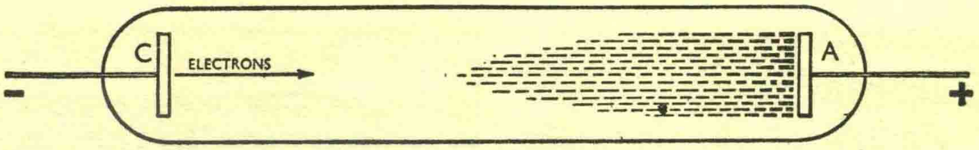
ing a battery and that the second person shall be able to detect the flow of current. A simple detector would be an ordinary lamp, which might be operated by means of a relay switch so that the wires between the two people do not have to carry the full power necessary to operate the lamp; such an arrangement is shown in the diagram. As this type of system cannot be used to transmit speech directly it is necessary to use some form of code such as that invented by Morse. In the Morse Code the electricity is made to flow for either a short period to produce a "dot" or for a longer period to produce a "dash". This type of code is used with automatic machines, which are able to recognize various combinations of electrical impulses. An important machine like this is the Teleprinter, in which a normal-looking typewriter keyboard is used but which, in addition to providing a typed symbol on the machine, sends out a series of electrical impulses to a distant similar machine on which the same symbol is simultaneously typed.

Much more common in the modern world is the Telephone, a device that does enable people to speak directly to each other over a distance. The telephone also depends upon an electric circuit between the two people communicating and it is the function of the telephone exchanges to establish such circuits either manually or automatically. The transmission of speech requires that a microphone be used to convert the vibrations of the air produced when a person speaks into electrical signals to be sent along the wires. A microphone suitable for this purpose has been described in the section "The Science of Electronics". The receiver is of the electromagnetic variety and consists of a diaphragm of iron mounted close to the pole pieces of a horseshoe magnet on the arms of which are wound coils of very fine wire. On passing the signals from the microphone through the coils the diaphragm vibrates and so reproduces the speech of the sender.



This diagram shows (on the right) the racks of an automatic telephone exchange. Each component is a "uniselector" connected to a subscriber's line. The uniselector is an ingenious switch that connects the caller to the number he dials. Inset at the top is the cable room underneath the exchange. This is where the wires from thousands of subscribers are collected together and passed to the meter racks. A manual switchboard is shown below for comparison.

Electric Discharges in Gases



A = anode, C = cathode. The glow around the anode disappears at very low pressures and cathode rays are produced.

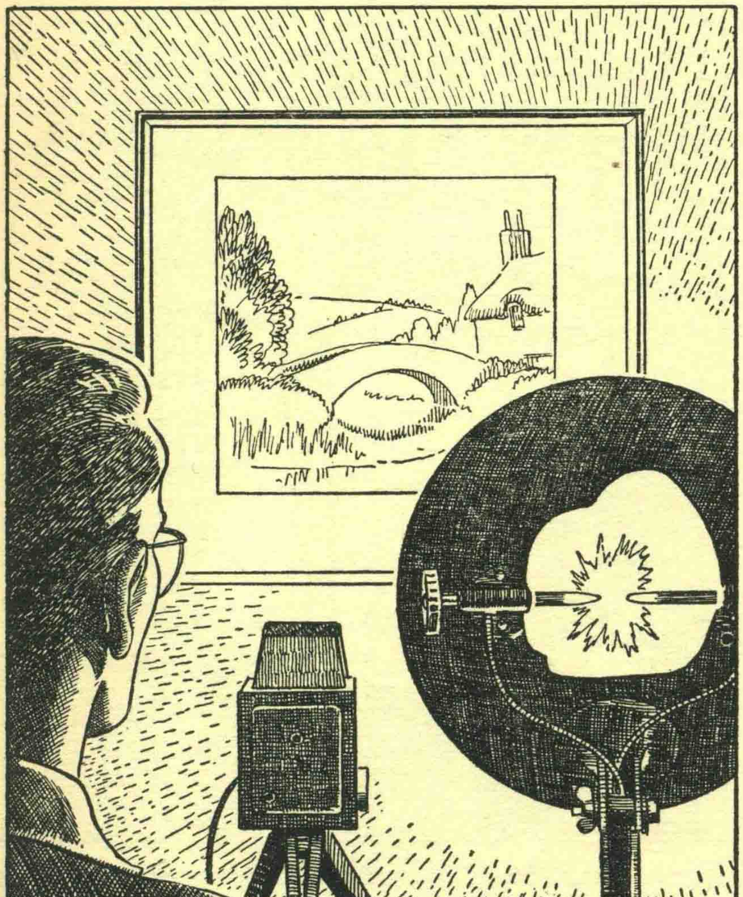
If a tube containing gas at a reduced pressure has a voltage stress between two electrodes placed in it, then under certain conditions of gas pressure and voltage stress, electrons being accelerated towards the anode will ionise the gas and the energy released on collision will appear as light of a colour characterstic of the gas.

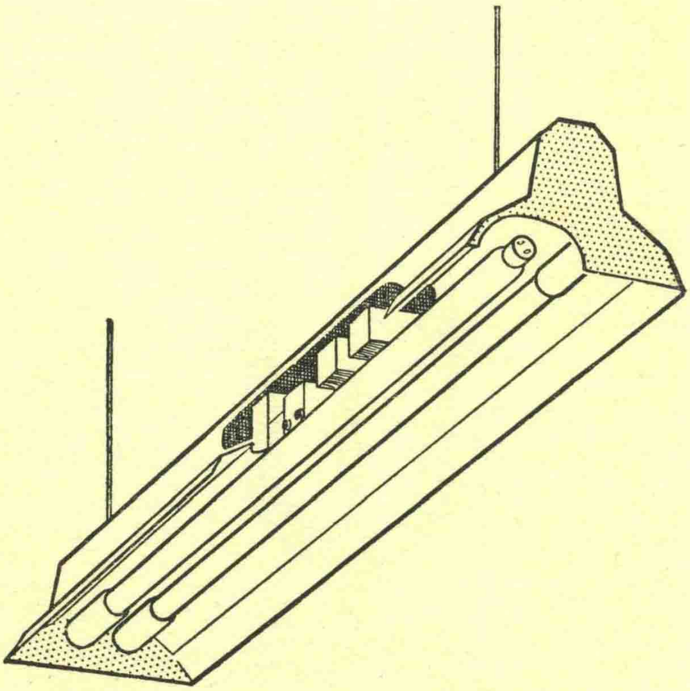
Use is made of this principle for mercury, hydrogen and neon lamps. Sodium lamps have a pre-heated cathode.

Fluorescent tubes are a further development. Here the tubes are filled with mercury vapour and the glass envelope coated with fluorescent powder; characteristic radiation from the mercury ions causes the powder to fluoresce. These tubes give a very efficient light output.

Arcing

If a sufficiently high enough voltage is applied between two carbon rods in air, a rapid ionisation of the air will occur characterised by a bright bluish glow. Large electric currents flow and the temperature in the vicinity of this arc is extremely high. This high temperature can be used to identify substances by spectral analysis (see page 10). Small metallic pellets attached to the ends of the carbon rods are vaporised by the high temperature of the arc and the characteristic radiations emitted by the gases formed are viewed by a spectrograph, by which means the substance of the pellet can be identified. The carbon arc is also used directly as a projector lamp, for studio lighting, and searchlights. If the arc is surrounded by the gas xenon, then an intense light closely resembling sunlight is obtained. This is used in studios for colour photography.





(*Left*) An arc lamp being used as a very bright source of light in photography.

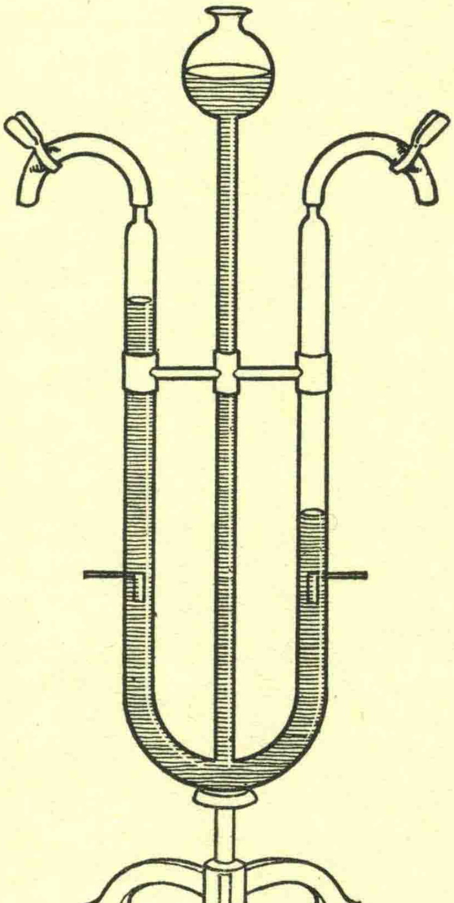
(*Above*) The fluorescent lamp is efficient because it does not waste energy as heat.

Electrolysis and Electroplating

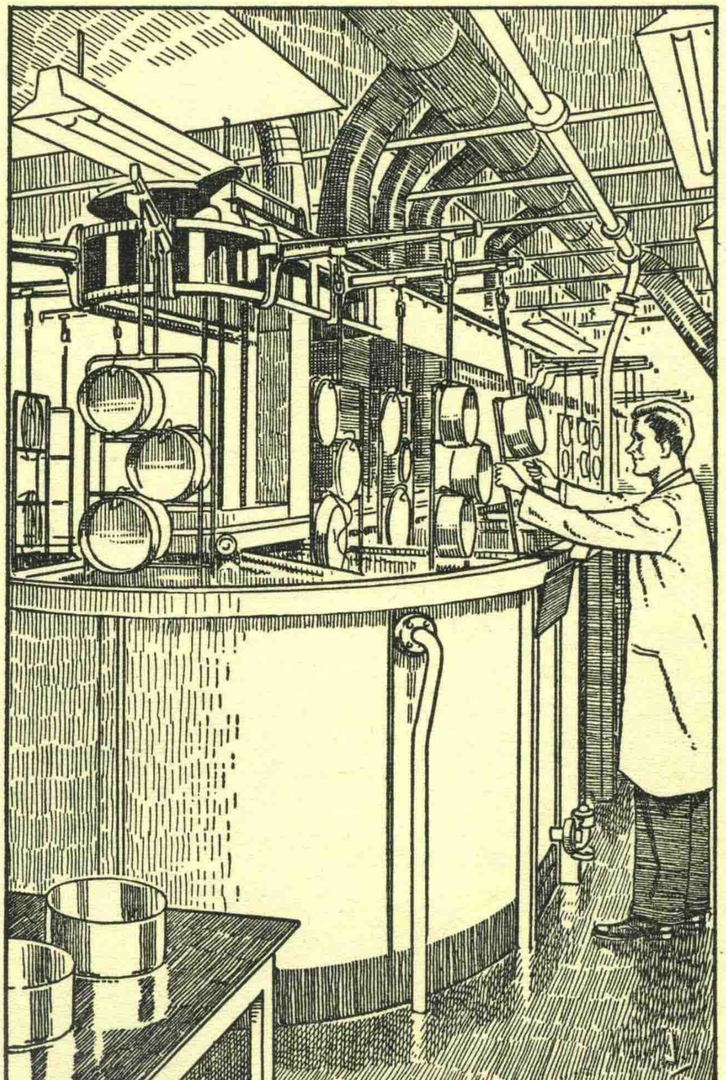
Solutions of chemical salts are conductors of electricity and a surprising relationship between chemistry and electricity is revealed when an electric current is passed through such solutions. A solution of hydrochloric acid contains ions of hydrogen with positive charges and chlorine with negative charges, and so it is to be expected that the hydrogen ions will be attracted towards the cathode, or electrode connected to the negative terminal of the battery. If the voltage applied to the cell exceeds a volt or so it is found that the hydrogen ions are converted to hydrogen gas and this appears as bubbles.

In a similar way the chlorine ions are attracted towards the anode where they are able to give up electrons and form molecules of chlorine gas which eventually appears as a gas after the solution has become saturated. If the electrode is made of a material that is attacked by chlorine the reaction is complicated by the fact that the electrode will probably dissolve.

One of the most important applications of electrolysis is that of electroplating. Here a solution of metallic salt is electrolysed, but instead of hydrogen being released at the cathode, metal ions collect there and on acquiring electrons are converted into the metal which under favourable conditions will be deposited as a smooth layer. Satisfactory electroplating requires careful attention to the chemistry involved and complications arise from the fact that a particular metal may not deposit equally well on other metals; thus steel will usually have layers of copper and nickel plated onto it before the final layer of chromium is deposited.



This laboratory apparatus, called a voltameter (not to be confused with a voltmeter), is used for the electrolysis of acidified water. The electrodes are made of platinum to resist corrosion.



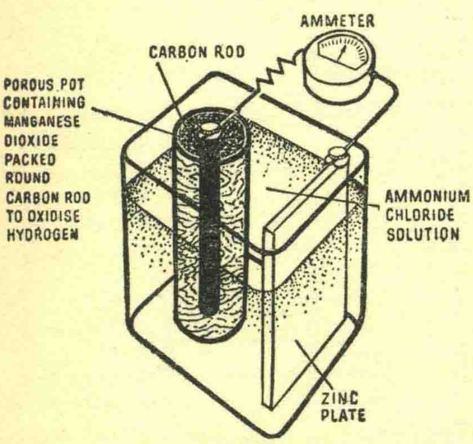
An industrial installation for chromium plating. The objects to be plated are hung from the cathode.

How Electricity is Made

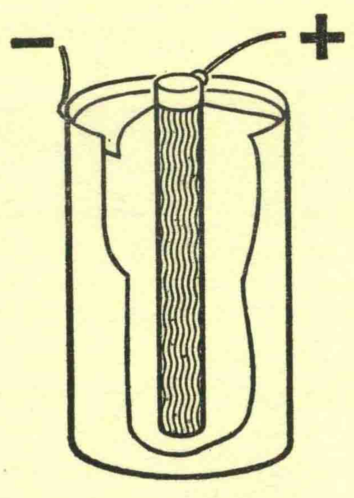
The production of electricity is achieved in two main ways. Most of it is made by electromagnetic machines, or dynamos, which are driven by steam turbines or other types of engine. The electricity made in this way is used as it is produced for the most part, since the storage of electricity in large quantities is not practicable. When only small amounts of electricity are required then this is frequently produced or stored chemically.

The chemical device in which electricity is made is called a cell, and a distinction is made between primary cells, which are used for the straightforward production of electricity from chemicals, and secondary cells, which are used for the storage of electricity. A battery consists of two or more cells connected in series.

One of the most important types of primary cell is that invented by Leclanché. In its wet form it consists essentially of a plate of zinc and a rod of carbon in a solution of ammonium chloride (or sal ammoniac). When the zinc and the carbon are connected by means of a conductor external to the cell, then it is found that electrons flow from the zinc to the carbon; that is, the zinc forms a negative electrode and the carbon a positive one; in addition the zinc dissolves in accordance with the equation:



The Leclanché cell is seldom used nowadays.



Most of the space inside a dry cell is taken up by the paste of carbon powder and manganese dioxide.

$$\underset{\text{Zinc}}{Zn} = \underset{\text{Zinc ions}}{Zn^{++}} + \underset{\text{Two electrons}}{2e^-}$$

On reaching the carbon the electrons attract ammonium ions from the solution and react with them to produce ammonia and hydrogen as follows:

$$\underset{\text{Two electrons}}{2e^-} + \underset{\text{Two ammonium ions}}{2NH_4^+} = \underset{\text{Two molecules of ammonia}}{2NH_3} + \underset{\text{One molecule of hydrogen}}{H_2}$$

Because the hydrogen is not a conductor of electricity the flow of current quickly falls to a very low level and the cell is said to be polarized. This difficulty can be largely overcome by surrounding the carbon rod with a paste of carbon powder and manganese dioxide, for the latter is capable of oxidizing the hydrogen to water, which does not interfere with the flow of current.

The familiar so-called dry cell is of the Leclanché type but the solution of ammonium chloride is made into a paste to avoid any risk of spillage.

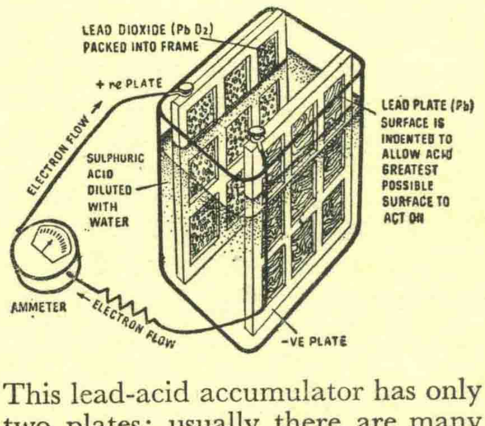
Primary cells are normally discarded when they have run down, but secondary cells, which we shall now consider, possess the advantage that they can be recharged and made as good as new by passing electric current, obtained from a generator, through them in the reverse direction to the one in which it flows when the cell is supplying power. By far the most common secondary cell is the lead acid accumulator. It consists of a solution of sulphuric acid in which are immersed two lead plates, one of which is covered with a paste of lead dioxide. When the cell supplies current lead dissolves at the pure lead plate and electrons are passed into the external circuit:

$$\underset{\text{Lead}}{Pb} = \underset{\text{Lead ion}}{Pb^{++}} + \underset{\text{Two electrons}}{2e^-}$$

Having passed through the external circuit the electrons react with lead ions (in the lead dioxide):

$$2e^- + \underset{\substack{\text{Lead ion}\\\text{(tetravalent)}}}{Pb^{++++}} = Pb^{++}$$

These reactions are reversed when current is passed in the reverse direction through the cell.

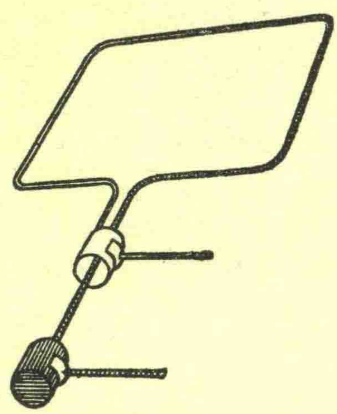


This lead-acid accumulator has only two plates: usually there are many pairs of plates wired in parallel. Porous separators prevent plates touching.

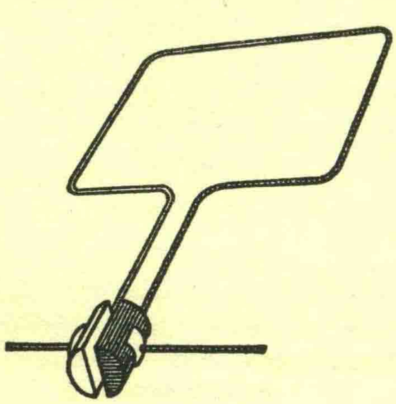
The Dynamo Principle

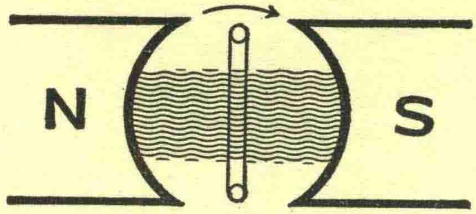
If the lines of force of a magnetic field are cut by a moving conductor, such as a length of copper wire, it is found that a voltage appears between the ends of the conductor. Similarly, a voltage appears at the ends of a coil of wire into which a bar magnet is moved, and it is important to note that the direction of the flow of electrons in the wire or coil, which is responsible for the voltage, is reversed as the relative motions of the magnet fields and conductors are reversed. Thus we have the exact reverse of the motor principle, and a machine that converts mechanical effort or work into electricity is called a generator or dynamo.

Basically the electric generator consists of a coil of wire

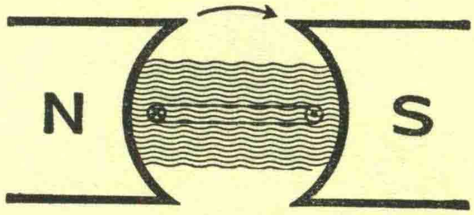


Above: slip-rings for A.C.
Below: commutator for D.C.

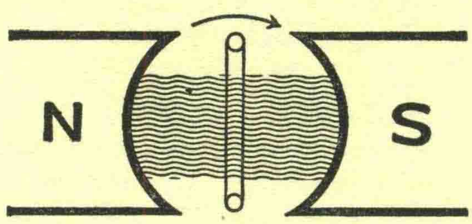




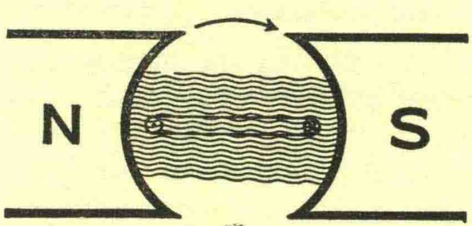
1. Coil is not cutting lines of force ∴ no current produced.



2. Many lines of force being cut ∴ large current produced.



3. Again no current produced.



4. Cycle is repeated as shown in graphs on right.

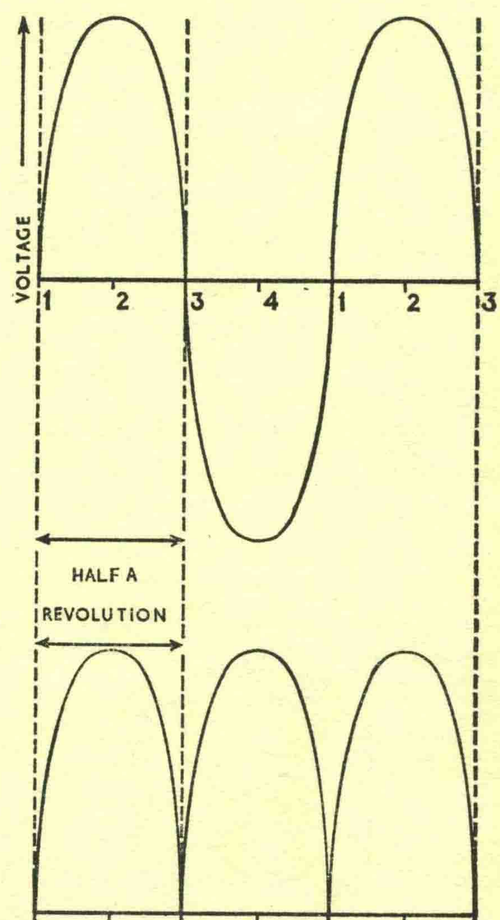
that is rotated in a magnetic field and has some provision for tapping off the electric current, usually by way of slip-rings on which bear carbon brushes as shown in the diagram. For half of each revolution of the coil the current in the external circuit flows in one direction, and in the other half it flows in the opposite direction, and such current is referred to as Alternating Current. If it is required that the current shall flow in only one direction then a commutator, such as is used in the electric motors already considered, can be used to achieve this by arranging that the external circuit is connected alternately to each end of the coil in turn and in step with the changes in direction of the voltage across the coil.

A good conductor (that is one with a low resistance) allows large currents to flow, a poor conductor allows only small currents to flow.

In electrical units the rate of doing work is designated by the WATT where

$$\text{WATTS} = \text{AMPS} \times \text{VOLTS}$$

The amount of electrical energy supplied is measured in KILOWATT HOURS (i.e. 1000 WATTS FOR A PERIOD OF 1 HOUR).



Variation of current with each position of coil using slip-rings (top) and commutator (bottom).

Ohm's Law

The relationship between current, voltage and resistance is known as OHM'S LAW.

VOLTAGE = CURRENT × RESISTANCE

The units used are:

VOLTS = AMPS × OHMS

Problems

1. A resistance of two ohms (2Ω) is connected across a twelve volt (12V) accumulator. What current flows?

Now VOLTS = AMPS × OHMS

$$\therefore \text{AMPS} = \frac{\text{VOLTS}}{\text{OHMS}} = \frac{12}{2} = 6 \text{ AMPS}$$

This resistor will release energy in the form of heat. The quantity of heat dissipated per second is measured in WATTS where WATTS = AMPS × VOLTS = 6 × 12 = 72 WATTS

2. A resistor of 6Ω is connected across a 12 volt accumulator. (a) What is the current drawn? A 2Ω resistor is then connected in SERIES with the 6Ω resistor (i.e. so that the current drawn flows first through the 6Ω and then the 2Ω resistor). (b) What is the new current drawn? (c) What would be the value of a single resistor to give the same total current?

VOLTS = AMPS × OHMS

i.e. 12 = AMPS × 6

$$\therefore \text{AMPS} = \frac{12}{6} = 2 \text{ AMPS}$$

Suppose current is i AMPS. The voltage across the 2Ω resistor would be 2i (OHM'S LAW). Similarly, voltage across 6Ω resistor would be 6i.

Now total voltage is that of the battery (12V).

$$\therefore 12 = 2i + 6i = 8i$$

$$\therefore i = \frac{12}{8} = \frac{3}{2} = 1.5 \text{ AMPS}$$

Note that $i = \frac{12}{8}$; i.e. it is the same as if we had connected only an 8Ω resistor across the battery.

3. A resistor of 4Ω is connected across a 12V accumulator. What current is drawn? A second resistor of 3Ω is then connected with the 4Ω resistor across the accumulator. What current does the 3Ω resistor draw? What is the total current drawn and find the resistance of a single resistor which would draw the same total current.

(a) Current drawn by 4Ω resistor is

$$\text{AMPS} = \frac{\text{VOLTS}}{\text{OHMS}} = \frac{12}{4} = 3 \text{ AMPS}$$

(b) Current drawn by 3Ω resistor is

$$\text{AMPS} = \frac{12}{3} = 4 \text{ AMPS}$$

Total current drawn is 4 + 3 = 7 AMPS

(c) Now $\text{AMPS} = \frac{\text{VOLTS}}{\text{OHMS}}$

$$\therefore 7 = \frac{12}{\text{OHMS}}$$

$$\therefore \text{OHMS} = \frac{12}{7}\Omega$$

It is interesting to note that we could have obtained the same result by simply adding together the reciprocals of the 4Ω and 3Ω resistors.

$$\text{i.e. } \frac{1}{4} + \frac{1}{3} = \frac{7}{12}$$

Series and Parallel Resistances

Where several resistances r_1, r_2, r_3, etc., are joined in *series* the value of the single resistance, R, which could replace them is given by:

$$R = r_1 + r_2 + r_3 +$$

Where several resistances r_1, r_2, r_3, etc., are joined in *parallel* the value of the single resistance, R, which could replace them is given by:

$$1/R = 1/r_1 + 1/r_2 + 1/r_3 +$$

4. A 2 kilowatt electric fire is to be run from the domestic supply (230 VOLTS) from a power point. What must the point be fused to? What is the resistance of the wire element at the operating temperature? If the fire is used for 5 hours per week over the winter period of 20 weeks, what will be the charge at the rate of 1d. per unit?

Now WATTS = VOLTS × AMPS

$$\therefore 2000 = 230 \times \text{AMPS}$$

$$\therefore \text{AMPS} = \frac{2000}{230} = 9 \text{ AMPS}$$

Theoretically a 10 AMP fuse would be sufficient. In practice we allow a tolerance factor and it would be quite normal to fuse such a point to 15 AMPS.

Now VOLTS = AMPS × OHMS

$$\therefore 230 = \frac{2000}{230} \times \text{OHMS}$$

$$\therefore \text{OHMS} = \frac{230 \times 230}{2000}$$

$= 26.5\Omega$

Total number of hours in use = 5 × 20 = 100 hrs.

Power consumed for a 2 kilowatt fire = 2 × 100 KILOWATT HOURS = 200 kW hrs.

Cost at 1d. per unit = 200 pence = 16s. 8d.

Glossary

Ampere. The unit of measurement of current flow. It is $\frac{1}{10}$ of an Electromagnetic Unit. It is also defined as the steady current which in 1 second passing through a solution of silver nitrate in water will deposit ·001118 gr. of silver (electrolysis). *See also* Ohm's Law.

Coulomb. The unit of measurement of the quantity of electricity flowing in a circuit. When a 1-ampere current flows for 1 second the quantity of electricity passing is 1 coulomb. *See also* Electrolysis.

Dyne. A unit of measurement of force of the C.G.S. system (Centimetres, Grammes, Seconds). One dyne is the force which acting on a mass of 1 gm. will give it an acceleration of 1 cm. per sec. It is a very tiny unit. A force of 1 gm. weight is g dynes (where g is the acceleration due to gravity), i.e. a force of 1 gm. = 981 dynes.

Electromagnetic Units. Relate the flow of current in a coil of wire to the strength of the magnetic field set up in the coil. One E.M.U. of current is the current that has to flow through a wire 1 cm. long and coiled as the arc of a circle whose radius is 1 cm. to produce a magnetic field at the centre of the circle of 1 gauss strength, or to exert a force of 1 dyne on a unit magnet pole placed at the centre of the circle.

Electromotive Force is the total Potential Difference that an electric cell or battery can produce. It is the Potential Difference between its terminals when no current is delivered by the cell (an "open circuit").

Electrostatic Units. Just as the north poles of two magnets repel each other, so two objects which are both positively charged repel each other. If a body is positively charged, and a unit positive charge is brought from infinity up to it against the mutual repulsion of their charges, and the amount of work done in moving it is 1 erg, then the potential at the first body is 1 E.S.U. *See also* Volt.

Erg. The unit of measurement of work done. When 1 dyne acts through a distance of 1 cm. in the direction of the force 1 erg of work is done. A more practical unit is the Joule, which is 10,000,000 ergs (10^7 ergs). One joule is the amount of work done when a 1-ampere current flows through a 1Ω resistance for 1 second. It is approximately $\frac{3}{4}$ ft.-lb.

Gauss. The unit of measurement of the intensity of a magnetic field. A magnetic field is of 1 gauss intensity when it acts with a force of 1 dyne on a unit magnet pole. The intensity of a magnetic field is represented diagrammatically as one line of force per square centimetre of the cross-section of the field for every gauss unit, so 10 Gauss would be considered as 10 lines of force in 1 sq. cm.

Joule (see **Erg**).

Law of Inverse Squares. Magnetic attraction or repulsion by one magnetic pole on another varies inversely as the square of the distance between them.

The same law applies to all radiations, light, heat, radio waves, etc.

Mechanical Equivalent of Heat. The heat generated in a circuit by a current I flowing through it is proportional to the resistance R, the time t, and the square of the current: Heat = I^2Rt. If I is in amperes, t in seconds, and R in ohms, the heat energy is found in joules. Calories are the physicists' usual measure of heat, and it has been experimentally checked that 1 calorie = 4·2 joules (this proportion is known by the symbol J), so

$$\text{Heat} = \frac{I^2Rt}{J} \text{ calories.}$$

Ohm. The unit of measurement of resistance, its symbol is the Greek letter Ω (omega). One Ω is the resistance of a column of mercury 106·3 cm. long and 1 sq. mm. in cross-section at 0°C. temperature.

Specific Resistance. The resistance between opposite faces of a centimetre cube of a material. This varies considerably according to the material. From the known specific resistance of a material, S, the resistance of a conductor made from it can be calculated.

$$R = \frac{Sl}{A}$$

where l is the conductor's length in cm., and A is its cross-section in sq. cm. For a circular wire the value of A will be $\pi \times \text{radius}^2$.

Unit Electric Charge (electrostatic) is the charge which exerts a force of 1 dyne on an exactly equal charge placed 1 centimetre from it in air.

SOME COMMON VALUES OF SPECIFIC RESISTANCE

The unit is the OHM-CM.

Silver	$1{\cdot}7 \times 10^{-6}$
Copper	$1{\cdot}8 \times 10^{-6}$
Aluminium	$2{\cdot}9 \times 10^{-6}$
Brass	$7{\cdot}0 \times 10^{-6}$
Iron	12×10^{-6}
Steel	20×10^{-6}
Mercury	95×10^{-6}
Nichrome	11×10^{-5}
Glass	5×10^{11}
Ebonite	2×10^{15}
Porcelain	2×10^{15}
Mica	9×10^{15}

Unit Magnetic Pole is that pole which is repelled by a force of 1 dyne by an exactly equal pole 1 centimetre away from it in air.

Volt. The unit of measurement of electrical pressure. The potential difference between two points is the work done in ergs (*see* Electrostatic Units) in moving a unit positive charge from one to the other. One volt is $\frac{1}{300}$ of an electrostatic unit of potential difference. It is also the potential difference between two points when 1 coulomb passes between them and 1 joule of work is done. *See also* Ohm's Law.

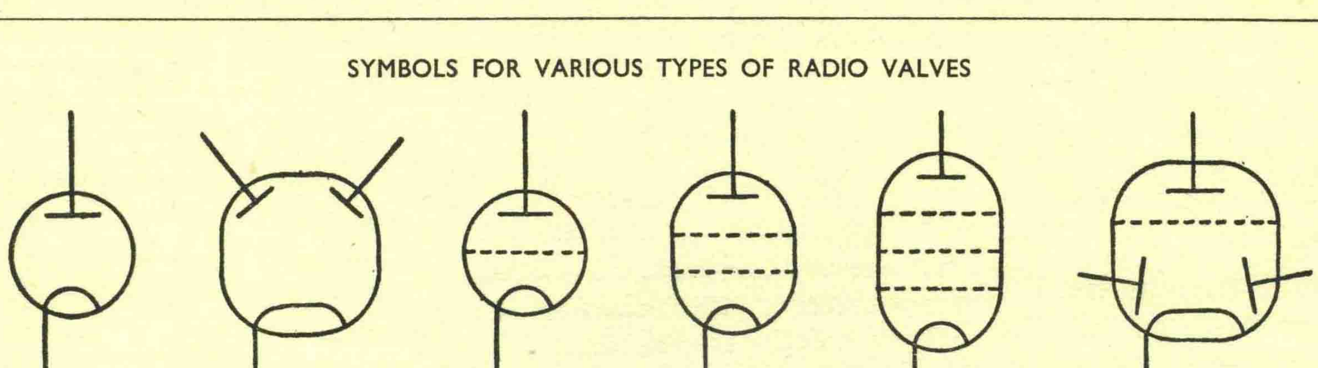
Watt. The unit of measurement of power used or needed in an electric circuit. One watt is 1 joule per second. In any circuit in which E volts potential difference causes Q coulombs of electricity to pass the work done in the circuit is EQ joules. As the coulomb is current (I) × time in seconds (t), EQ can be expressed as EIt. One volt is the PD when 1 coulomb passes and 1 joule of work is done (*see* Volt). So if EIt joules of work are done in t seconds, then EI joules are done in 1 second, i.e. the power is EI watts. Watts = Volts × Amperes.

An electric lamp is marked 240 volts, 60 watts: therefore the current will be

$$I = \frac{W}{E} = \frac{60}{240} = \frac{1}{4} \text{ amp.}$$

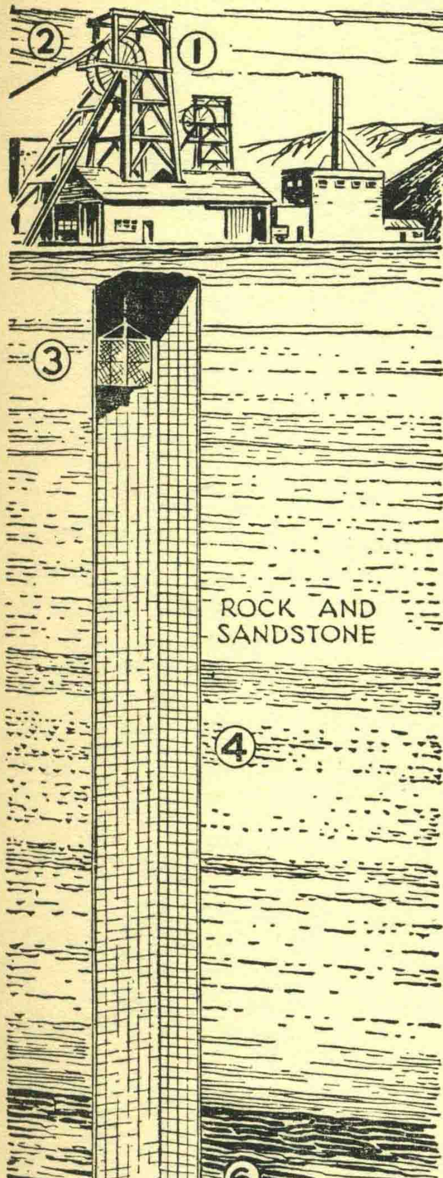
Note: Since E = IR, we can express work done as I^2Rt instead of EIt joules (*see also* Mechanical Equivalent of Heat).

SYMBOLS FOR VARIOUS TYPES OF RADIO VALVES



DIODE DOUBLE DIODE TRIODE TETRODE PENTODE DOUBLE DIODE TRIODE

COAL AND OIL

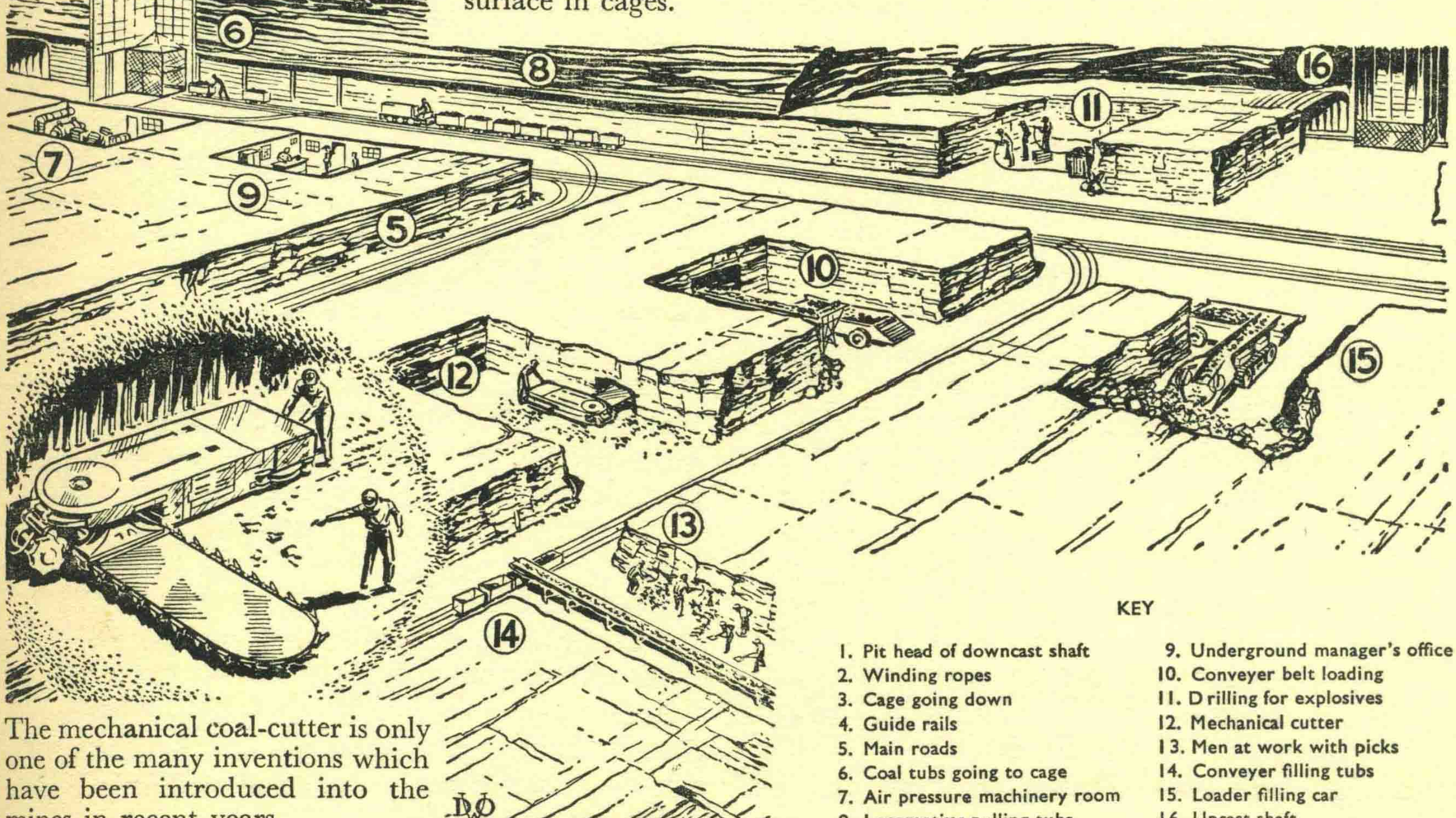


At the present coal and oil provide most of the world's power. They may be used to produce electricity in power stations or they may be used directly as a fuel in industry and in the home.

Though coal has been known and used for thousands of years, it was not until the 14th century that coal was mined underground. Until then it was dug from small outcrops which were abandoned as soon as the surface coal had been removed. The modern version of this is opencast mining, which is carried out on a much larger scale with mechanical shovels.

Underground coalmining has completely changed in character during the last few hundred years. At one time working conditions were incredibly bad and the risk of fire and explosion very great. The customary method of ventilation in 1700 was to light a fire at the bottom of the shaft, thus creating a draught which largely cleared the foul air from the mines. Needless to say, this was a frequent cause of explosions. The invention of the safety lamp by Sir Humphry Davy had an immediate effect in reducing the number of pit disasters.

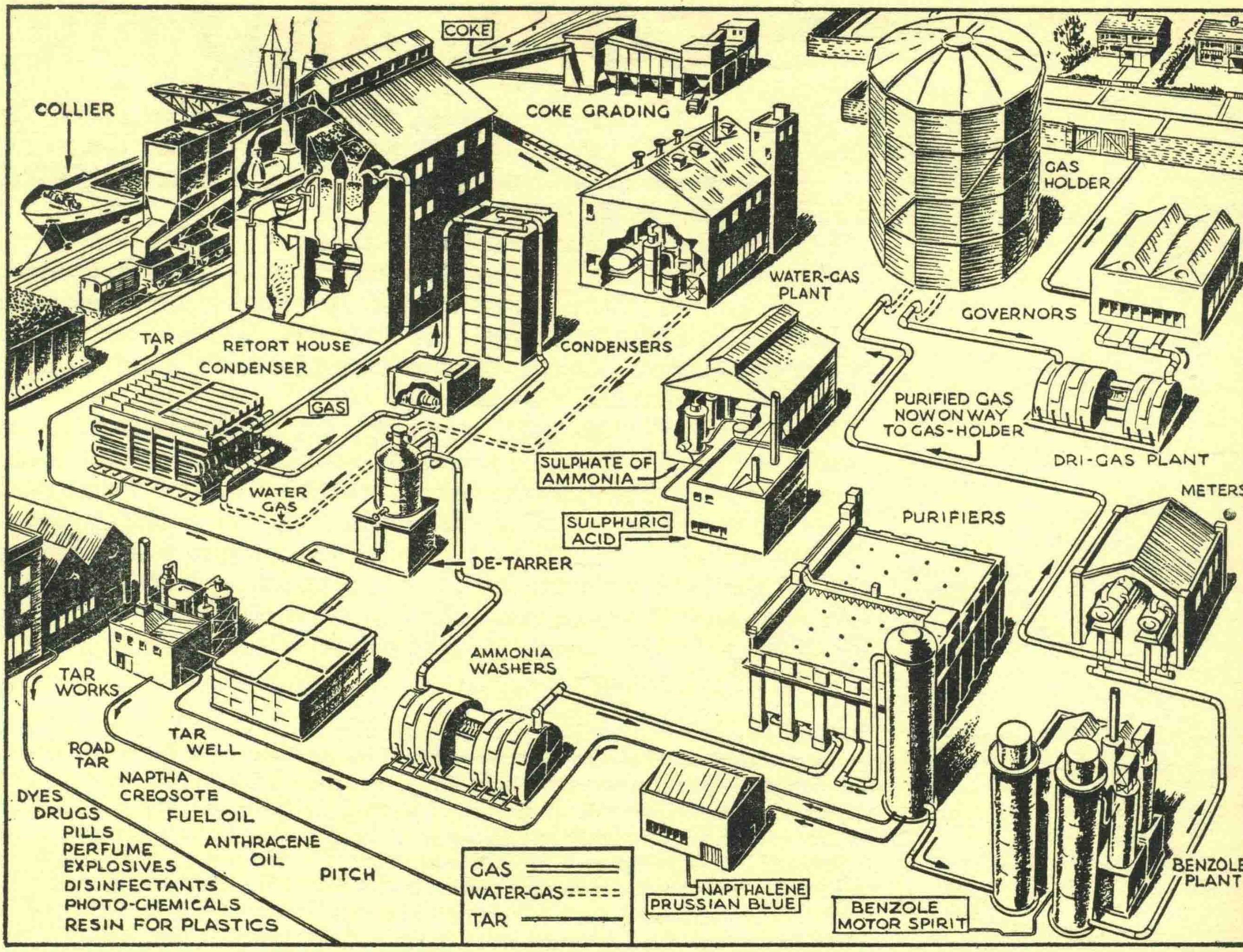
In the pillar and stall method of underground mining, the coal seam is divided up into a number of blocks by a series of roads. Each block is cut inwards from the outside edge towards the centre, and when each has been cleared, the roof, which has been supported by pillars, is allowed to collapse. The whole width of the seam is cut at once when the long walling method is used, the roof being supported by pit props as the coal is removed. The seam is cut through at the bottom by an electrically driven cutter, and if this is not sufficient to make the coal fall, an explosive charge is used. The coal is then taken to the up shaft in small wagons running on rails or on conveyer belts and is then hauled to the surface in cages.



KEY

1. Pit head of downcast shaft
2. Winding ropes
3. Cage going down
4. Guide rails
5. Main roads
6. Coal tubs going to cage
7. Air pressure machinery room
8. Locomotive pulling tubs
9. Underground manager's office
10. Conveyer belt loading
11. Drilling for explosives
12. Mechanical cutter
13. Men at work with picks
14. Conveyer filling tubs
15. Loader filling car
16. Upcast shaft

The mechanical coal-cutter is only one of the many inventions which have been introduced into the mines in recent years.



A diagrammatic view of a gasworks, showing the general layout and the sequence of processes. Some of the installations are not usually found within the gasworks itself, but are separate from it.

Mechanisation in the coal industry has led to the smaller mines becoming uneconomical units and in many cases they have been closed down. The large modern mine is far removed from the old "holes in the ground". Today, a miner may travel several miles into the earth and then cover a similar distance by diesel train to the coal face. The network of underground roads is often like the road system of a small town, although it may be built at several levels.

Coal is a mixture of free carbon and a large number of valuable chemicals containing carbon atoms. It is used as an industrial and domestic fuel and in power stations to generate electricity. More efficient use is made of coal in a gasworks where it is separated into its constituent parts. A diagram of the working of a gasworks is shown above.

In a gasworks coal is heated in ovens which air is not allowed to enter. A brown gas is given off and coke is left behind. The brown gas is led to a condenser where part of it liquefies as a black tarry material which we call "coal tar". The "coal gas" which passes through the condenser is washed, purified and stored in the familiar gas-holders. One ton of average coal will yield about half a ton of coke, 14,000 cu. ft. of gas, and over 10 gallons of coal tar. Coal gas and coke are both valuable fuels, the latter being used in large quantities in the smelting of iron ore. Although the black sticky coal tar may appear to be of little value, in fact quite the reverse is true.

Coal tar is a complicated mixture of carbon chemicals and, like crude oil, the constituent parts can be separated by fractional distillation (see page 191). The chemicals which are obtained from this process are used in the manufacture of an almost incredible range of synthetic materials.

The Oil Industry

In a hundred years, oil has established itself as one of the world's most important natural materials. The world's consumption is almost a million times more than the 1,000 tons used in 1860, and today about half of the world's energy requirements are met by oil.

It is generally thought that crude oil was formed from 10 million to 400 million years ago, and is derived from the decayed bodies of masses of tiny sea creatures. While this dead organic matter decayed it became covered with layers of fine sediment. As their weight increased, these sediments became compressed into rock strata which sealed in the decaying mixture. Although the oil deposits were originally laid down on the sea bed, the continual change in the earth's contours explains why oil is often found hundreds of miles from the sea, and sometimes under a desert.

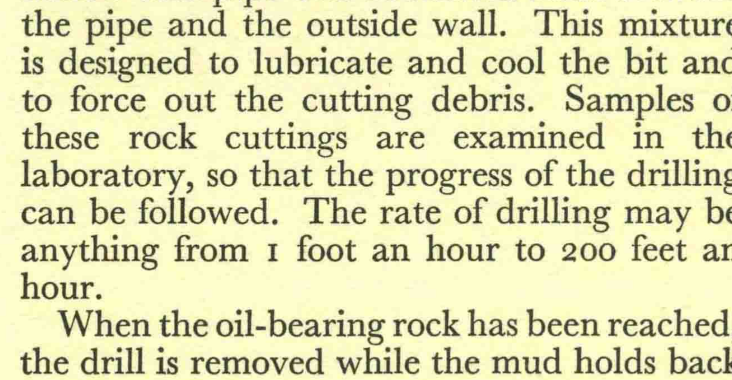
Underground deposits of oil often have natural gas and water associated with them. These deposits are held in subterranean traps which have been formed by the movement of the earth's rock layers. The petroleum geologist searches for these traps by studying the nature of the earth's strata with the aid of aerial photographs. He is also helped by various scientific instruments including the gravity meter and the seismograph. The gravity meter measures the gravitational pull of the earth at a particular point, and this depends on how dense the rocks are immediately below that point. The seismograph is normally used for measuring earthquakes. The oil geologist creates his own small earthquake with dynamite and then records the waves which are reflected up from the layers of rock beneath him. The strength and nature of these waves vary with the position and type of surface from which they are reflected.

Even when the geologist has collected all his clues he still cannot be certain about the presence of oil. The only way to find out is to drill a well, and this is an expensive business. There are two main methods of drilling, both of which use a supporting tower or oil derrick.

Cable tool drilling consists of repeatedly raising and dropping a heavy cutting tool hung on a cable. This is the older of the two methods and today most wells are drilled by the rotary method. The principle of rotary drilling is exactly similar to that of a carpenter's brace and bit. The drill pipe is usually about 5 inches in diameter and it is added in sections as the cutting bit forces its way down, often to a depth of two or three miles. Drilling mud, which is a special mixture of clay, water and chemicals, is pumped down the hollow drill pipe and circulated back between the pipe and the outside wall. This mixture is designed to lubricate and cool the bit and to force out the cutting debris. Samples of these rock cuttings are examined in the laboratory, so that the progress of the drilling can be followed. The rate of drilling may be anything from 1 foot an hour to 200 feet an hour.

Changing the bit on the drill while boring for oil. Continual friction against the rocks means considerable wear on the bit. (Inset) a "Christmas tree".

When the oil-bearing rock has been reached, the drill is removed while the mud holds back the flow of oil. Tubing is then lowered into the well to carry the oil out, and at the surface an arrangement of valves and pipes is fitted called a "Christmas tree". This controls the flow of oil into the surface tanks, and when the derrick is removed it may be the only indication of the well beneath it.

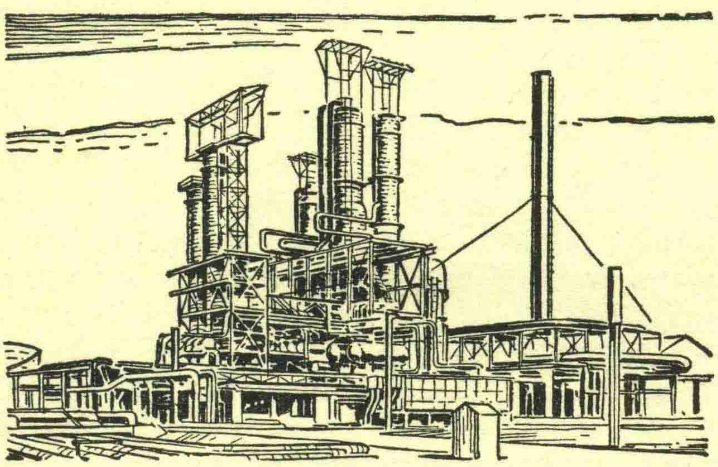


An oil trap. Bore holes sunk quite close together may strike oil, gas, water, or nothing at all.

The Uses of Oil

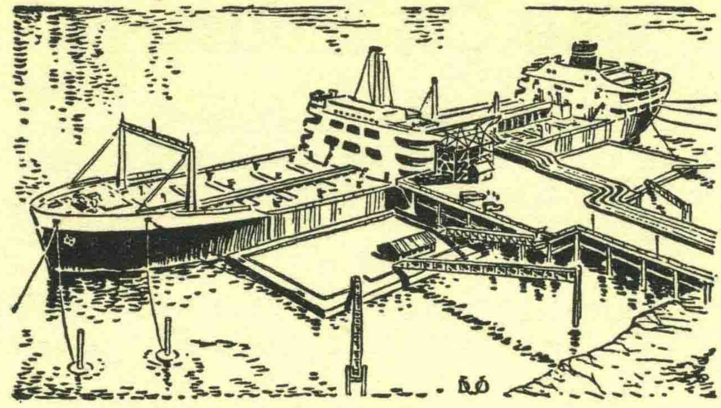
Crude oil, as it comes out of the ground, is a variable material of little immediate value. Although no two batches of crude are the same, they are all alike in that they consist mainly of a complicated mixture of hydrocarbons—that is, compounds containing only carbon atoms and hydrogen atoms. These compounds will range from gases, with simple molecules, through liquids, to solid waxes with large numbers of hydrogen and carbon atoms in their molecules.

The first stage in refining is distillation, a method of sorting out the mixture of hydrocarbons into "fractions" of similar molecule size (see page 70).



The distillation unit of an oil refinery. The apparently complex apparatus is used to separate out various grades of oils from the crude petroleum by means of distillation (see page 70).

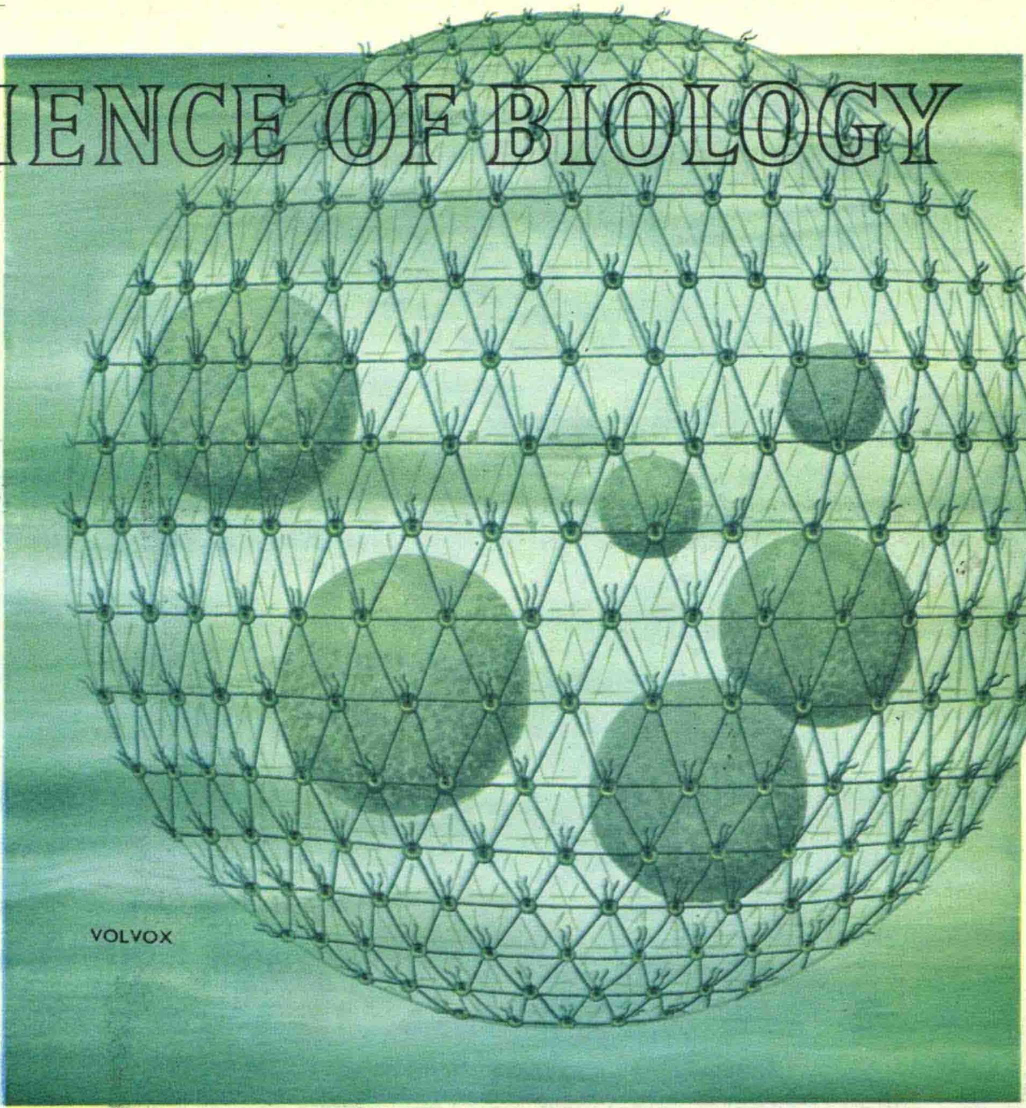
Crude oil will yield fractions of gas, petrol, kerosene, fuel oil, lubricating oils and asphalt. If distillation were the only process in refining, we should be able to get these fractions only in the proportions which exist in the natural crude oil. Frequently, commercial demand is for more of one fraction and less of another. For example, crude oil contains about 20% of motor fuel, but this amount is not nearly sufficient to meet today's demand for petrol. Petroleum chemists have met this challenge by finding ways of changing the molecular architecture of the hydrocarbons to increase the yield of a particular fraction. In the process called "cracking" large hydrocarbon molecules are broken down into much smaller molecules, whilst, on the other hand, "polymerisation" and "alkylation" are methods of building small molecules into larger ones. This chemical juggling has enabled the refineries to convert every drop of crude oil into useful commercial material.



An oil tanker discharges its cargo at a refinery jetty. Refineries are often built near the coast so that the oil can be pumped directly between ship and shore.

In addition to the increased yields of petrol, cracking produces large quantities of certain gases. It was soon realised that these gases could be easily converted into useful organic chemicals, and in only about 30 years a new industry of petroleum chemicals has grown up.

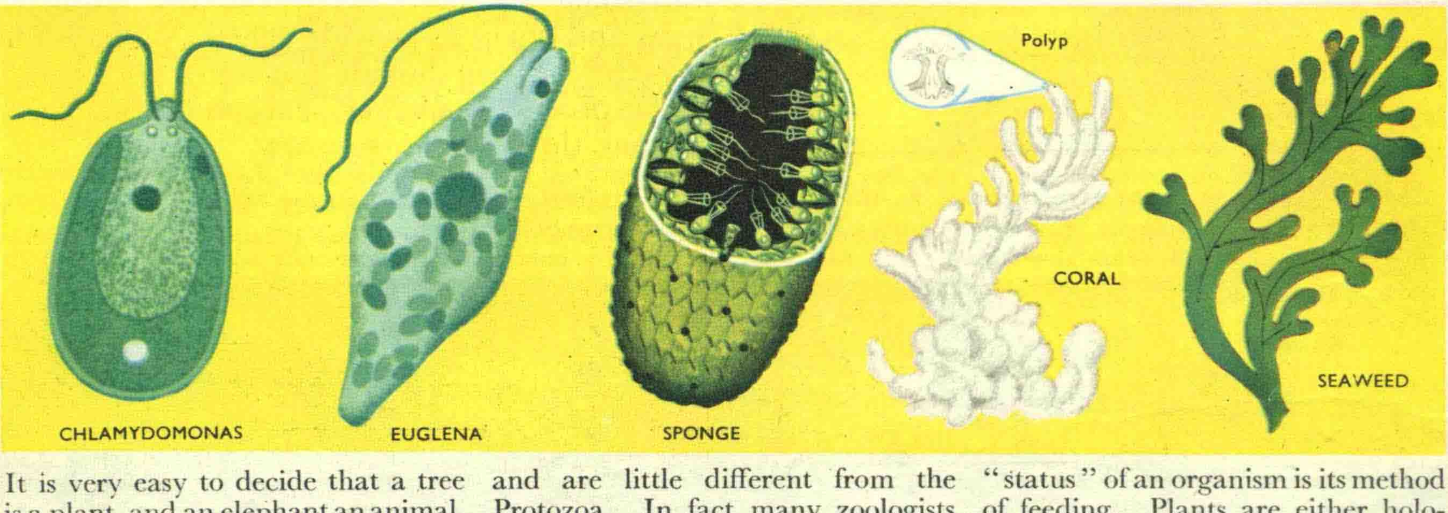
THE SCIENCE OF BIOLOGY



Biology, since it is the study of living things, includes classification, anatomy, physiology and evolution. It covers every aspect of life.

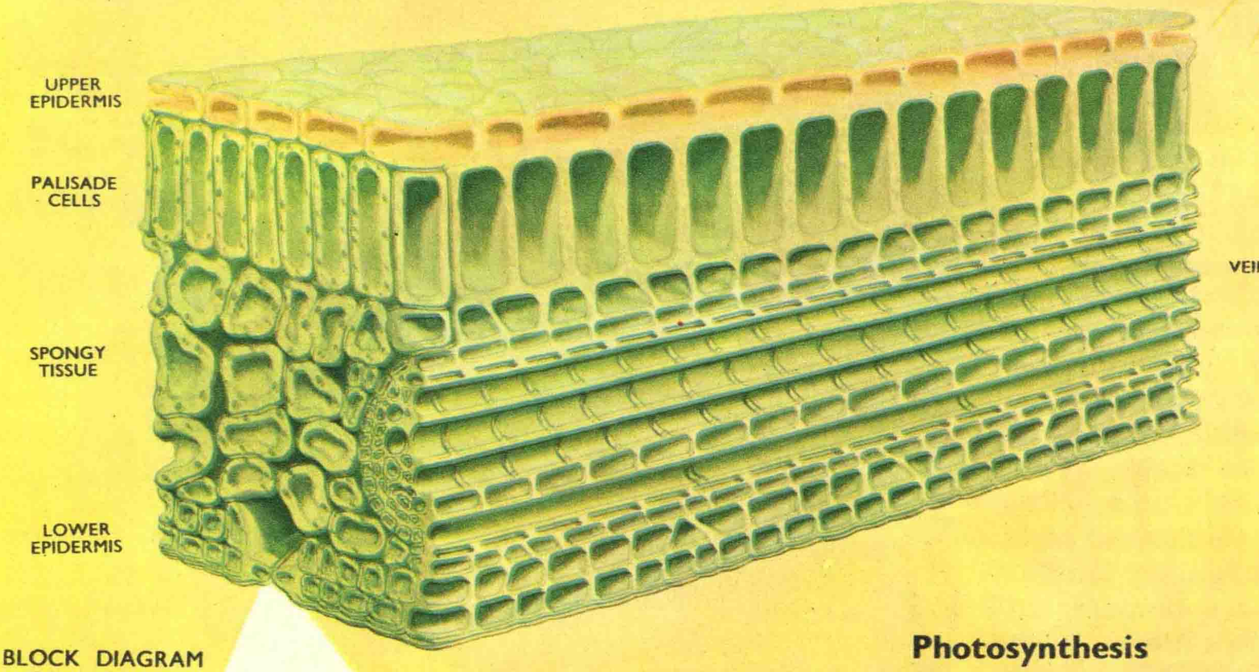
The earth is thought to be more than two billion years old, yet life has probably existed for less than half that time, and man himself only one million years. No fossils are known in rocks of Pre-Cambrian origin (Page 229). Cambrian rocks, some five hundred million years old, contain the earliest known fossils. There are various theories as to the nature and origin of Pre-Cambrian life.

It seems probable that the very early forms of life were merely complex organic molecules capable of reproducing like images of themselves, perhaps similar to some viruses, only free-living. Later forms may have had the ability to make their own food like bacteria, and then came the ability of some forms to photosynthesis (Page 34). From these primitive single-celled forms came animals with cells grouped together like the sponges, and these may have given rise to many celled forms. Gradually the vertebrate level of organisation was evolved, reaching its present peak with the advent of man. Evidence for animal and plant evolution from a common "stock" is very great, and comes from the study of fossils (Page 129), genetics, embryology, and comparative anatomy (see Glossary).

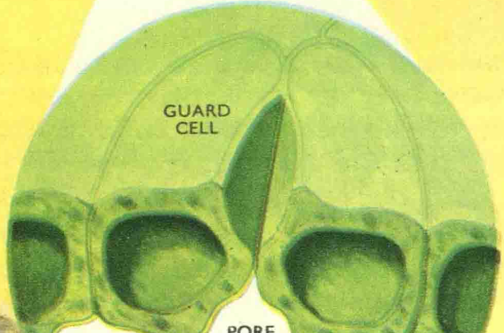


It is very easy to decide that a tree is a plant, and an elephant an animal. Forms like *Euglena*, *Chlamydomonas*, and *Volvox*, are much harder to place, and are little different from the Protozoa. In fact many zoologists class *Euglena* as an animal. One factor which helps to determine the "status" of an organism is its method of feeding. Plants are either holophytic or saprozoic. Animals are usually holozoic (see Glossary).

How Plants Live



BLOCK DIAGRAM OF PART OF A LEAF



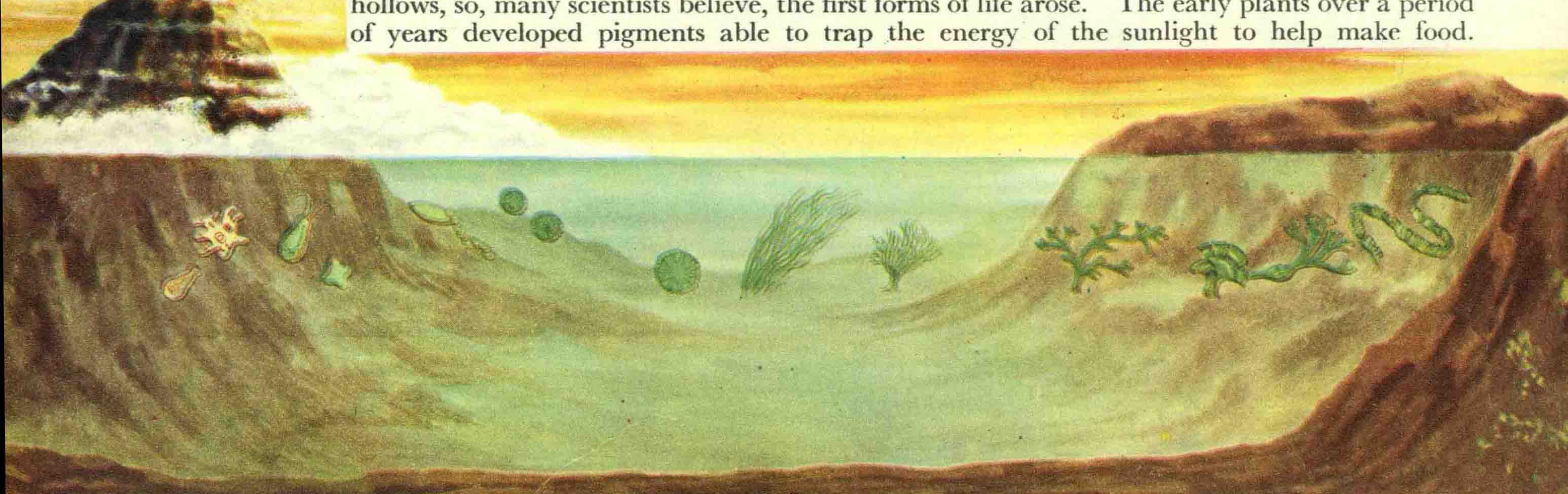
Stomata usually consist of two bean-shaped *guard cells* which surround a narrow slit-like pore.

Photosynthesis

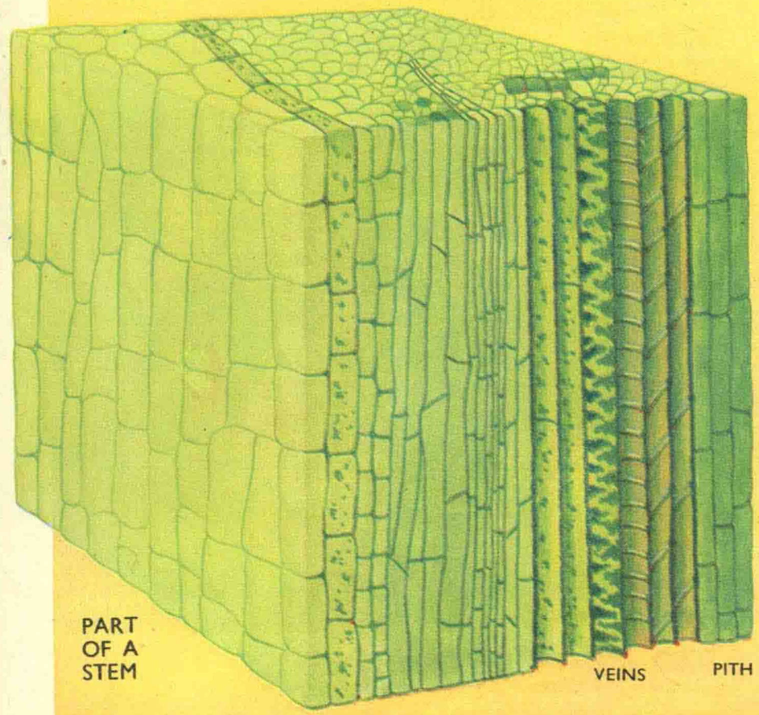
During the day the sun's rays pass through the leaf's skin (*epidermis*). Small holes (*Stomata*) in the epidermis allow carbon dioxide to pass into the palisade cells. Here a green substance, *chlorophyll*, converts the light of the sun into energy used to form sugars (*carbohydrates*), and finally starch, a complex carbohydrate, from the carbon dioxide and the water absorbed by the roots.

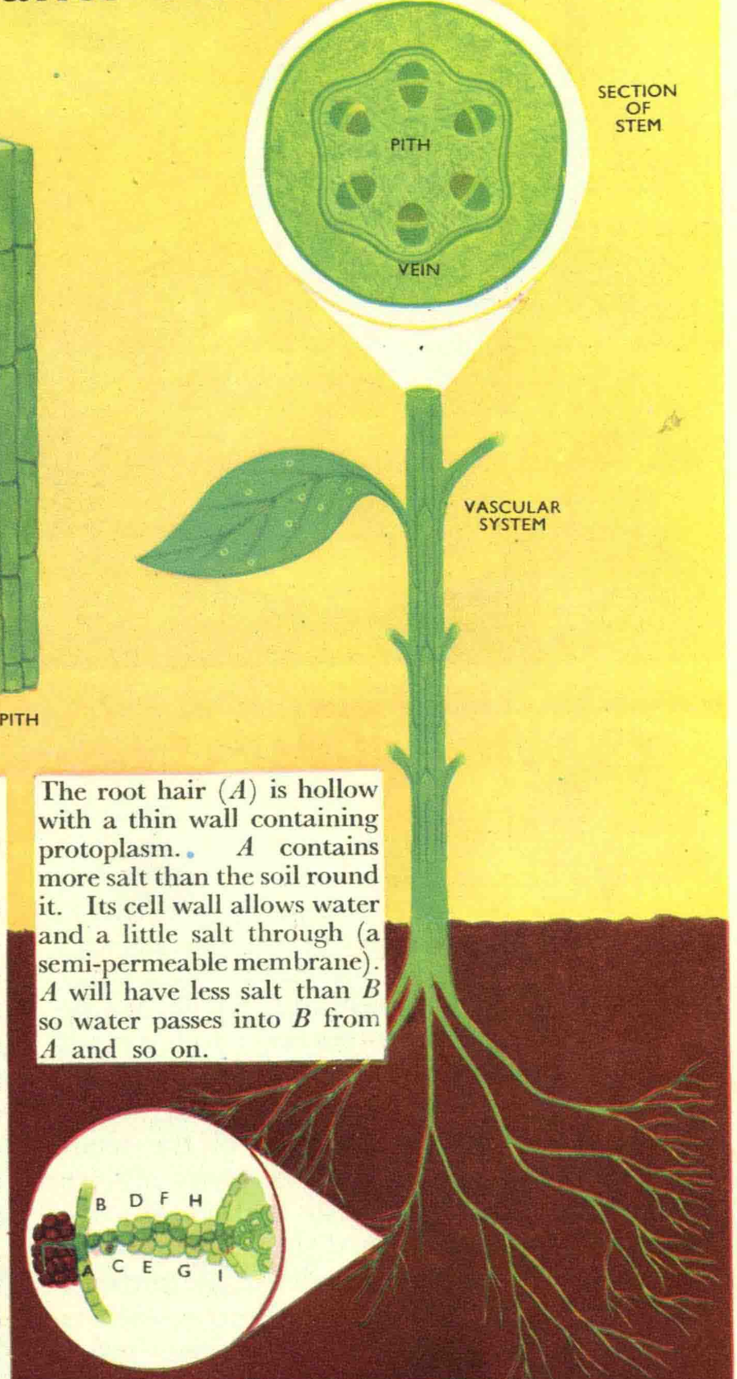
All day the leaves make starch. Oxygen formed passes out through the stomata. At night no starch is formed as the chlorophyll receives no light. The starch grains are turned into sugar which is carried to the required areas and burnt to provide energy, perhaps for growth. Carbon dioxide and water are formed in this process (*respiration*), carbon dioxide passing out through the stomata.

Plant Evolution. As the earth's surface cooled and water became trapped in the rock hollows, so, many scientists believe, the first forms of life arose. The early plants over a period of years developed pigments able to trap the energy of the sunlight to help make food.



How Plants Feed

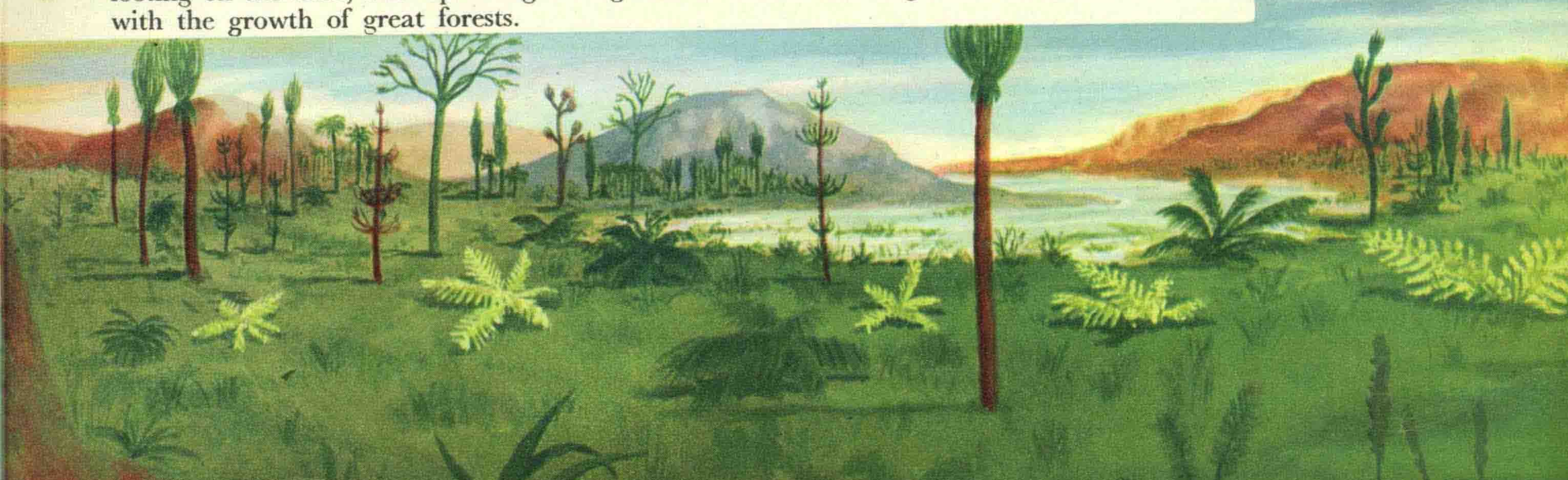




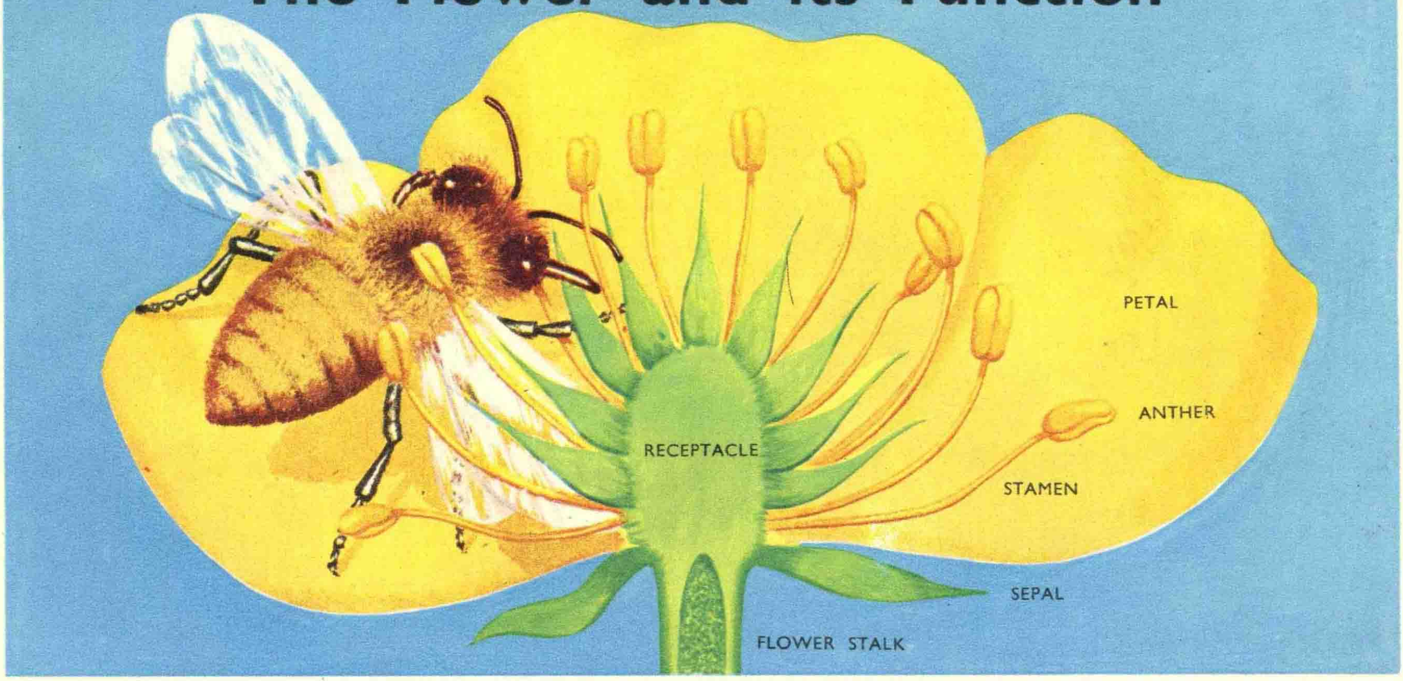
The root hair (*A*) is hollow with a thin wall containing protoplasm. *A* contains more salt than the soil round it. Its cell wall allows water and a little salt through (a semi-permeable membrane). *A* will have less salt than *B* so water passes into *B* from *A* and so on.

In the stem are the channels (*vascular system*) through which the fluid taken in by the roots passes to the leaves and the rest of the plant. Water enters a plant through the root hairs by *osmosis* (see Glossary) and eventually reaches the vascular tissue. The pressure at which this happens is termed *root pressure* and helps the water to rise a little way up the stem. The way in which the water travels from here to the leaves of a tree several hundred feet high is remarkable. The sun evaporates some of the water from the leaves through the stomata so that water is sucked up from below to replace it (*transpiration*). Water is very important to a plant as it is a medium for transferring soluble materials (*e.g.*, sugar, salts) from one part to another.

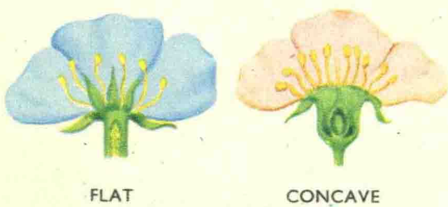
The earth's surface became still cooler, and many mountain ranges were formed before the coming of the first land plants at the end of the Silurian age. Plants gradually attained a footing on the land, after spending a long time in marsh and bog conditions, and flourished with the growth of great forests.



The Flower and its Function



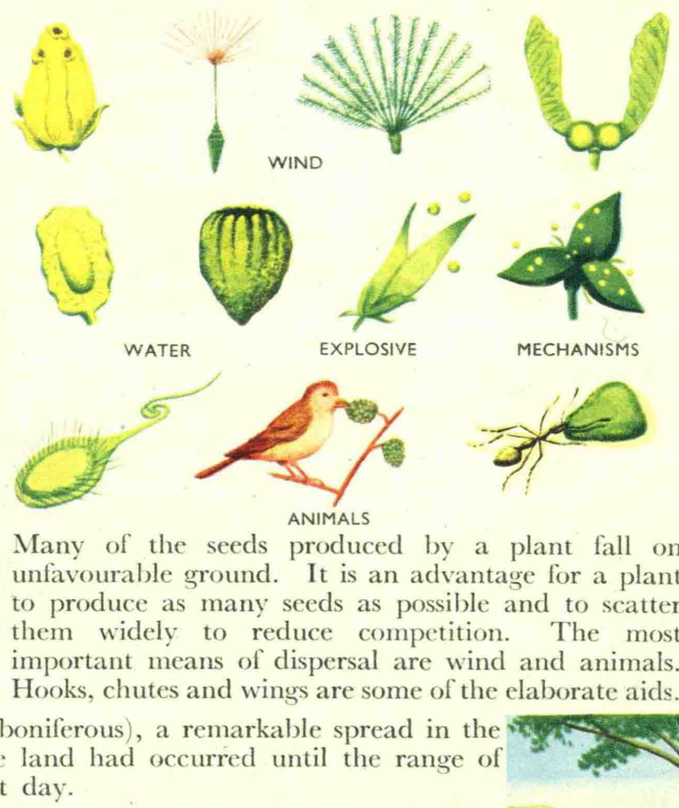
DIFFERENT TYPES OF RECEPTACLES



Flowers are very specialised fertile young shoots and are of great importance to the plant since they produce the seeds which maintain a plant's race. The stamens and the ovary are essential for the production of the seeds while the petals and the calyx (*perianth*) are partly protective, and also attract insects. Before a seed can be formed the ovule must be fertilised by the pollen produced in the anthers.

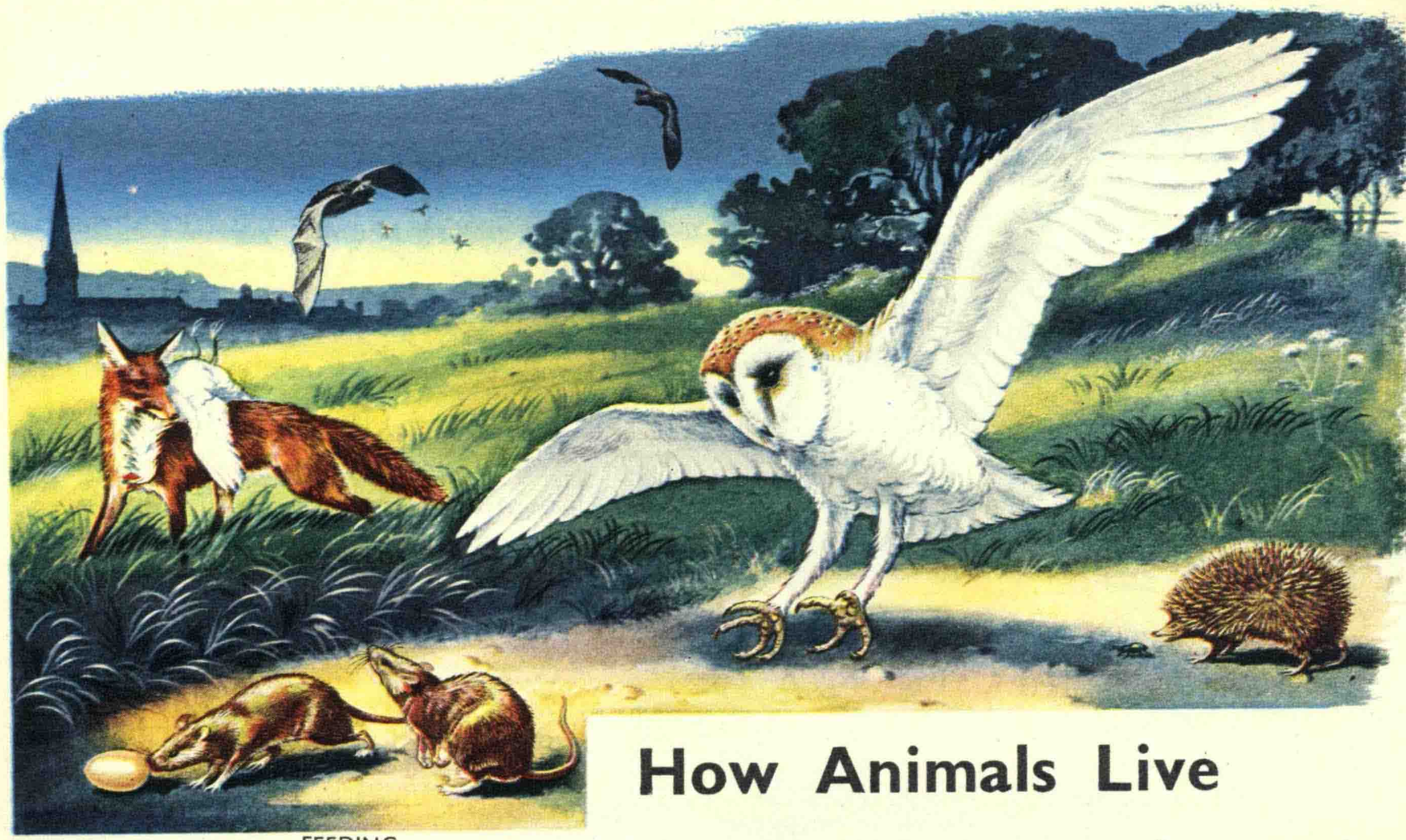
The expanded end of the flower stalk is termed the *receptacle*. This shows great variation in form and helps to determine the form of the fruit and the method of dispersal.

SEED AND FRUIT DISPERSAL



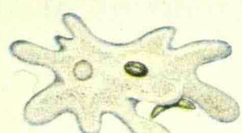
Many of the seeds produced by a plant fall on unfavourable ground. It is an advantage for a plant to produce as many seeds as possible and to scatter them widely to reduce competition. The most important means of dispersal are wind and animals. Hooks, chutes and wings are some of the elaborate aids.

Before the end of the coal forest era (Carboniferous), a remarkable spread in the distribution of plants to every part of the land had occurred until the range of plants almost equalled that of the present day.



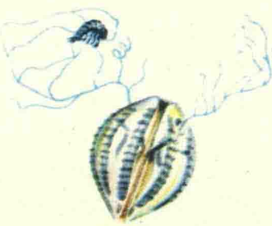
How Animals Live

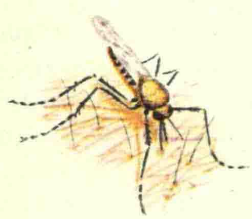
FEEDING



The *ctenophore* (below) has long sticky tentacles with which it traps its food.

Amoeba (above) puts out small projections (pseudopodia) which surround its prey, drawing the prey into the cell.





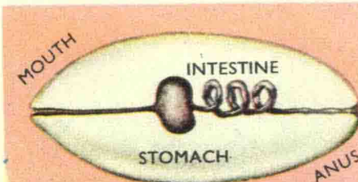
A female mosquito has piercing mouthparts. The long pointed "spike" can penetrate human skin. The spike is used to suck up the blood on which it feeds.

Vultures are scavenging birds which live mainly on the remains of dead animals, victims of preying forms or the elements.

Animals, like plants, live in fierce competition with one another. Those best suited to their surroundings have the best chance of survival.

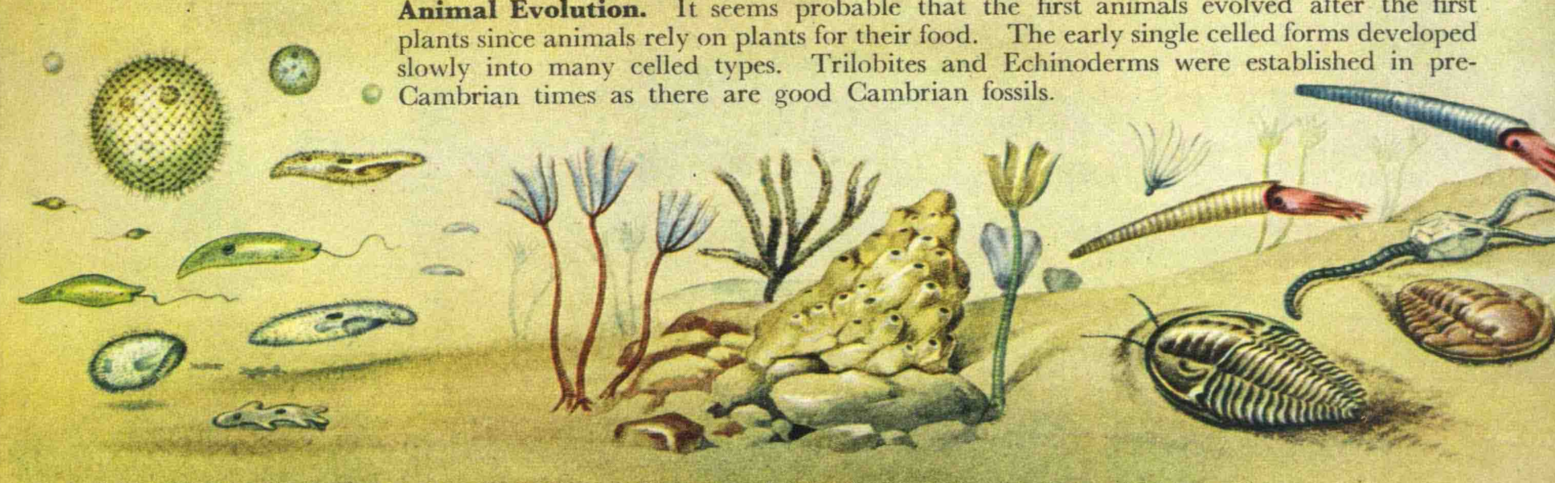
What are the problems which animals have to face? Of prime importance is the amount of food and water available. If a land animal relies on a source of water or food that becomes exhausted, unless it can find an alternative source it will die of thirst or starvation. Too much water in the form of a flood and it will drown, while a water animal might suffocate if its environment dries up.

DIGESTION

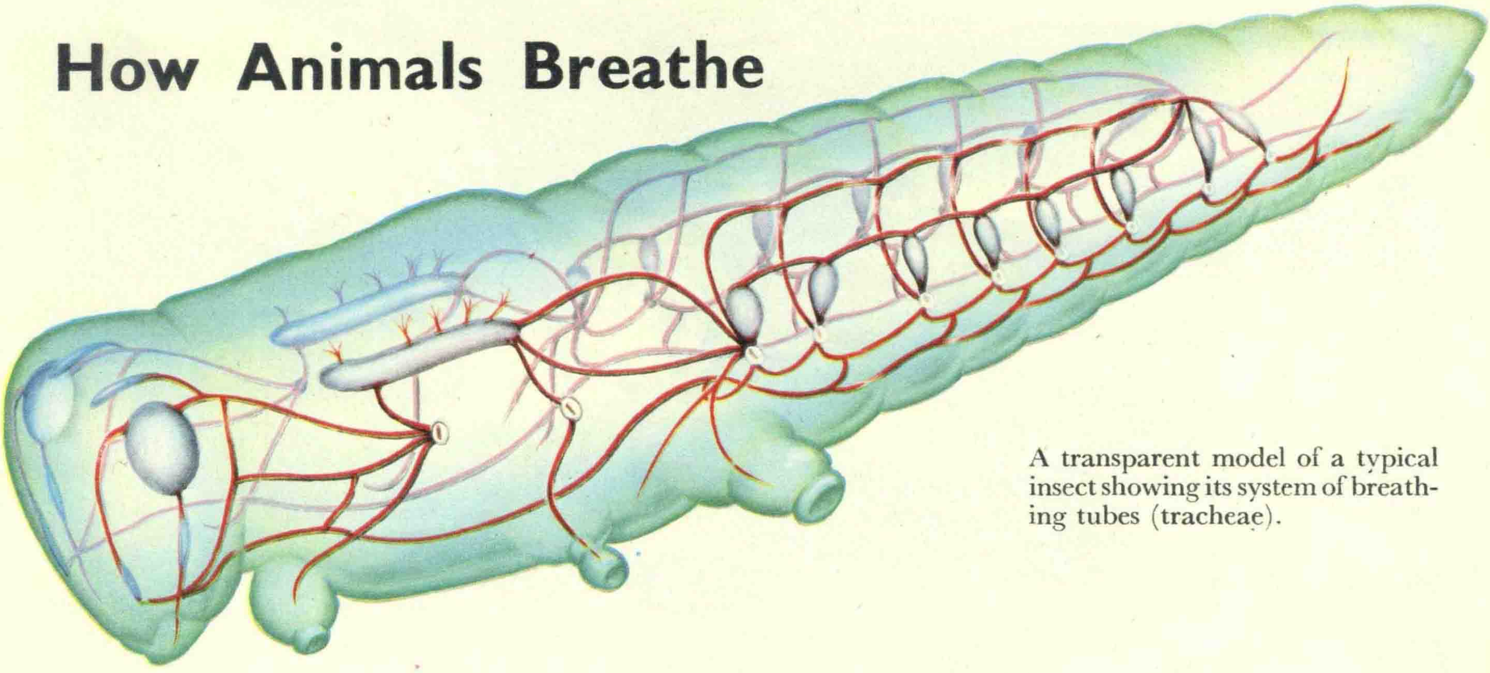


The diagram on the left shows the basic parts of the digestive system of animals, excepting the very simple forms. The relative size of parts depends largely on the type of food.

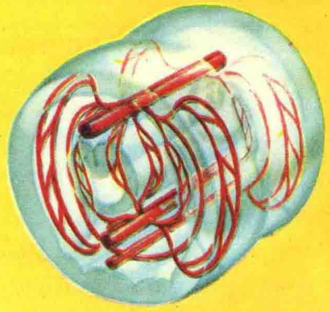
Animal Evolution. It seems probable that the first animals evolved after the first plants since animals rely on plants for their food. The early single celled forms developed slowly into many celled types. Trilobites and Echinoderms were established in pre-Cambrian times as there are good Cambrian fossils.



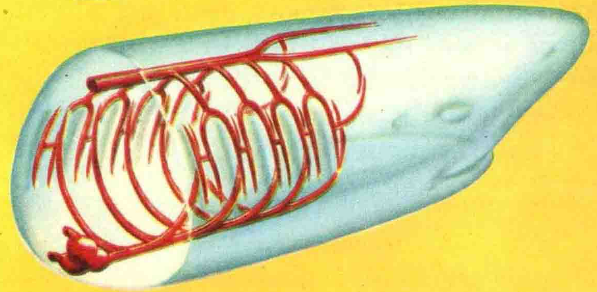
How Animals Breathe



A transparent model of a typical insect showing its system of breathing tubes (tracheae).



The skin of the earthworm is well supplied with blood vessels since this is the respiratory surface of the animal. It is always kept moist as this helps in the " absorption " of oxygen into the blood. The diagram (left) shows the blood supply to a segment.



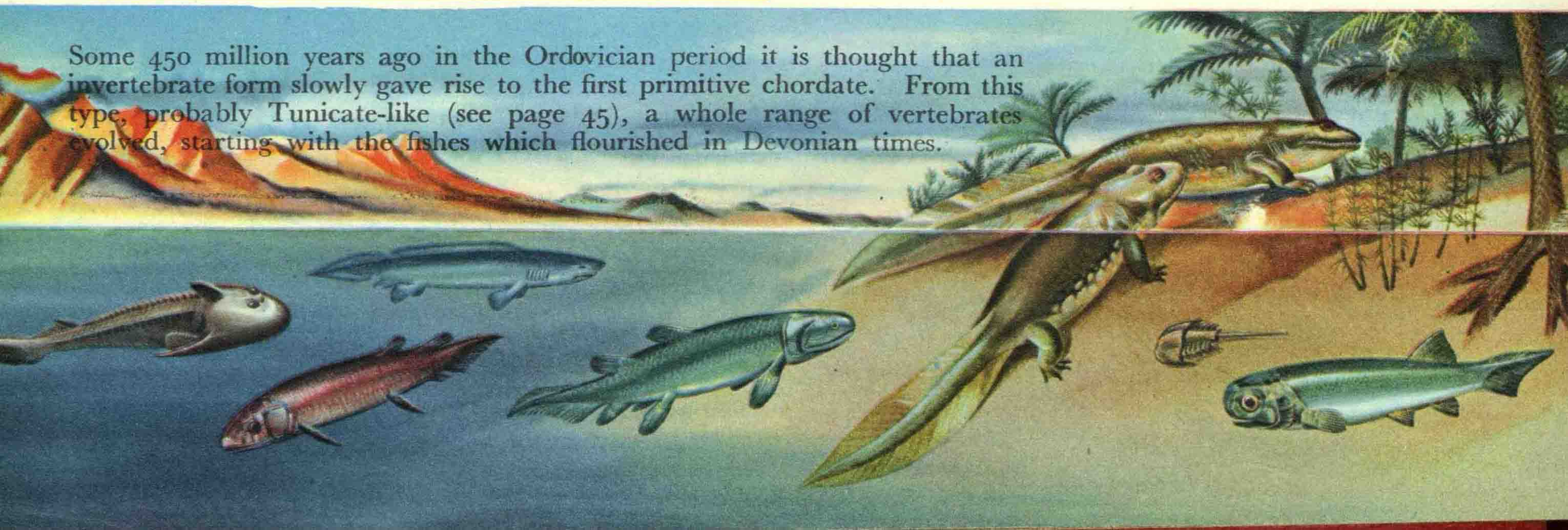
Sharks have varying numbers of gill slits on either side of the " throat ". These slits are lined by the gills, respiratory tissue well supplied with blood vessels. Water goes into the mouth and out through the gills, oxygen being taken into the blood and carbon dioxide removed.

Respiration not only includes carbon dioxide and oxygen exchange (breathing) at the respiratory surface (*e.g.*, skin, gills), but also tissue respiration—the " burning " of chemicals in the tissues to produce energy. Here we are concerned with the former process, the mechanical part of respiration and its link up with the blood stream.

Amoeba, a small animal can take up oxygen direct from the water by diffusion (see Glossary). This can only be effective in a small animal as the distance which oxygen can pass through a tissue in a great enough quantity to keep it alive is very small. A larger animal needs a transport system to carry oxygen round the body. This is the blood system.

The earthworm is the simplest animal to have a blood system. Oxygen passes in by diffusion through the skin. In fish, special respiratory surfaces (gills) are concentrated in the " throat ". Higher animals have lungs. Respiratory surfaces have a good blood supply.

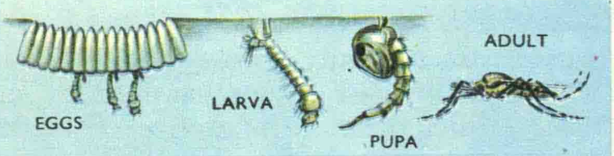
Some 450 million years ago in the Ordovician period it is thought that an invertebrate form slowly gave rise to the first primitive chordate. From this type, probably Tunicate-like (see page 45), a whole range of vertebrates evolved, starting with the fishes which flourished in Devonian times.



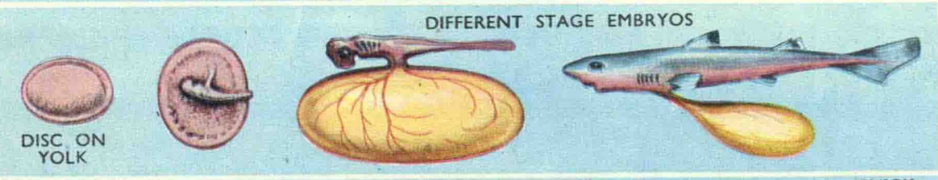
Reproduction

Reproduction is characteristic of living things. Animals are able to divide into two new individuals so that both halves are similar, or lay eggs which develop into similar individuals to the parents.

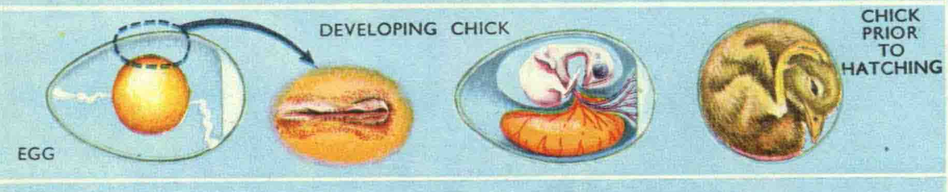
Most animal groups reproduce sexually, that is by the union of two cells, a small egg from the mother and an even smaller sperm from the father. This union is known as *fertilisation*. The fertilised egg (*zygote*) then divides repeatedly, forming many cells so that an *embryo* is formed. This eventually develops into an image of the adult. Development may be internal as with mammals, or external as with insects which lay eggs.



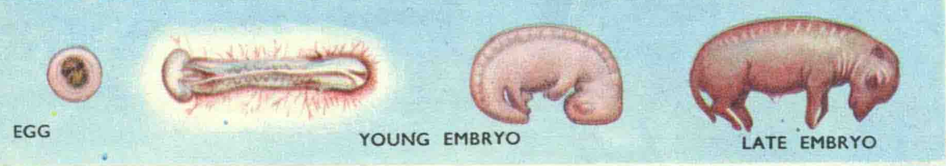
The changes in form of a developing insect are called *metamorphosis*. There are several distinct stages quite unlike the adult (*e.g.*, larva).



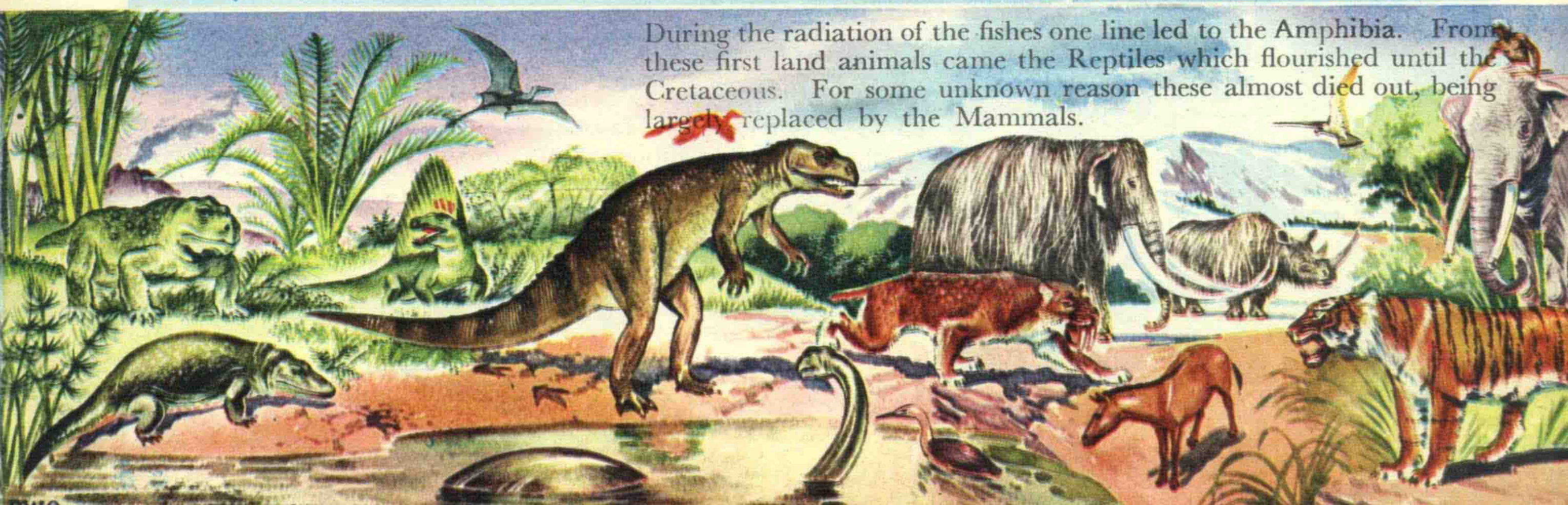
The shark embryo develops as a small disc of cells on top of the egg yolk. Gradually this enlarges to give the body form of the young shark.



The bird embryo develops as a small disc of cells on top of the yolk, in a similar manner to the shark. At birth the chick almost fills the shell.

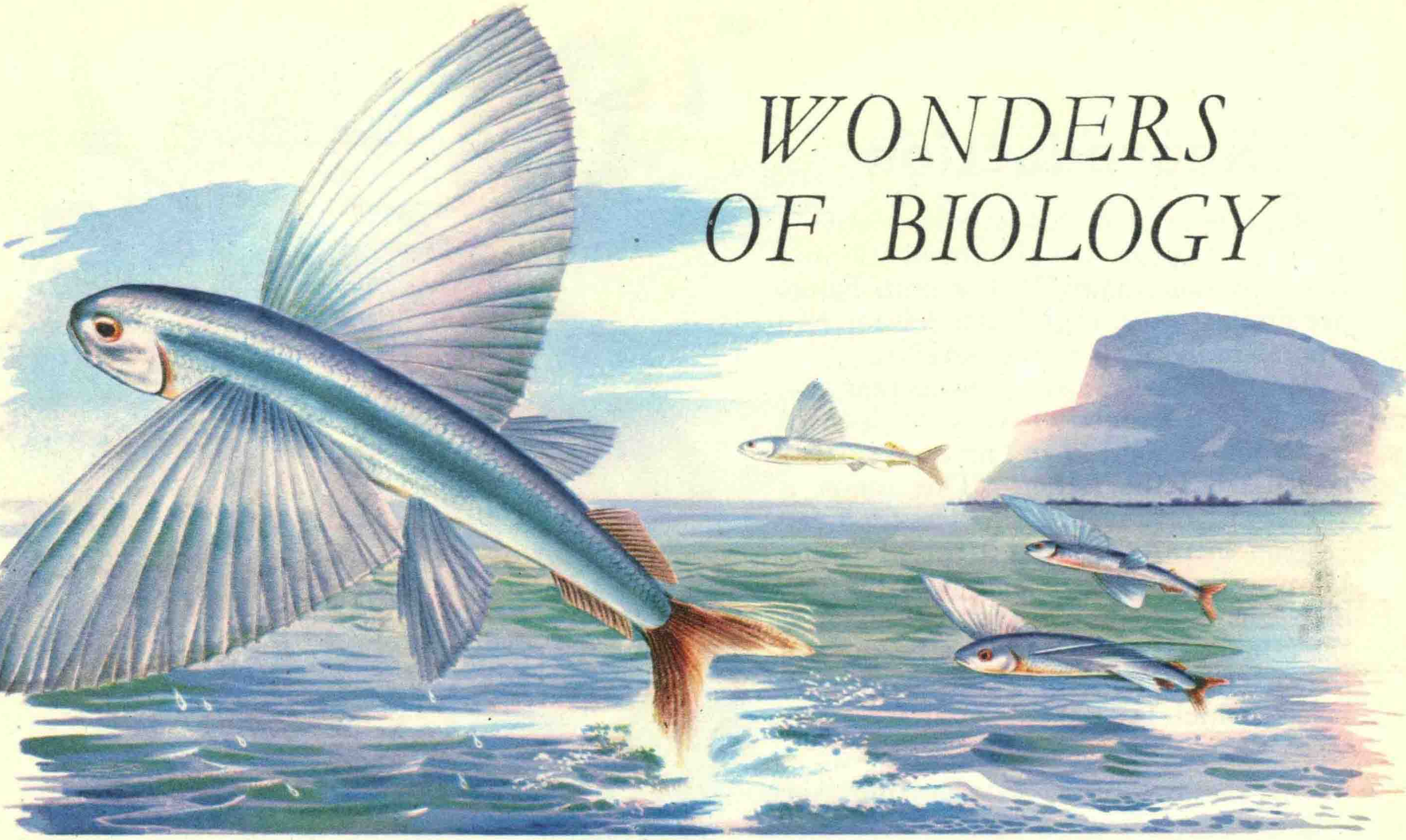


In mammals development is somewhat similar to the bird and the shark. Head development, however, is emphasised earlier on. The embryo develops inside the parent and not in an egg.



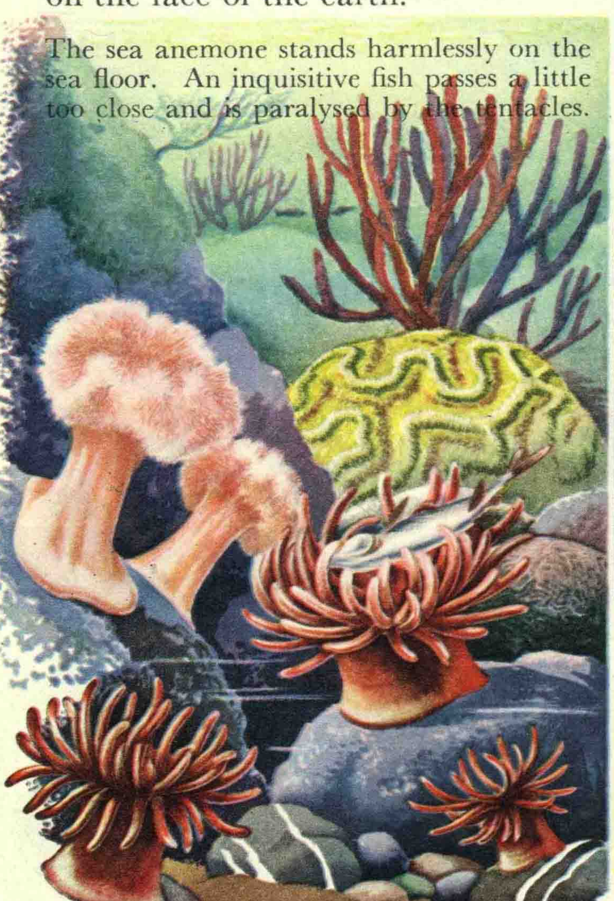
During the radiation of the fishes one line led to the Amphibia. From these first land animals came the Reptiles which flourished until the Cretaceous. For some unknown reason these almost died out, being largely replaced by the Mammals.

WONDERS OF BIOLOGY

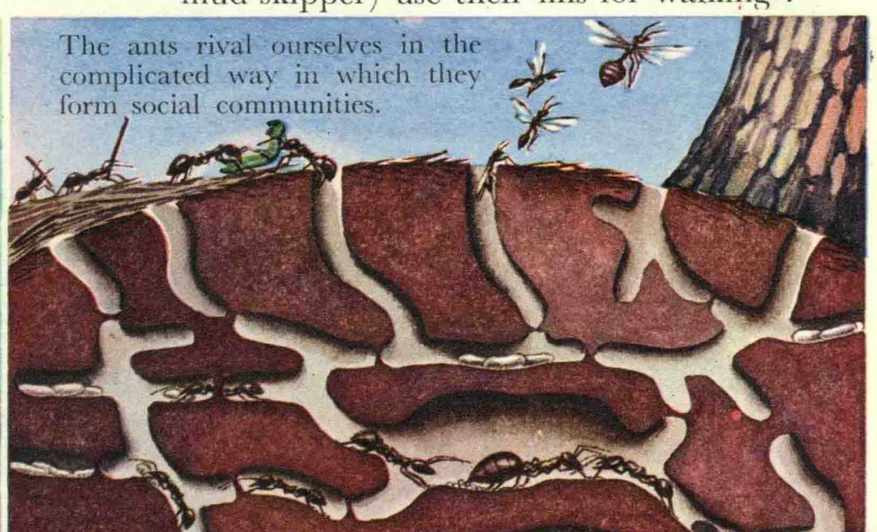


Many fantastic forms have existed in the past. The wonders of the present day, however, overshadow even those of the past. Dinosaurs were gigantic creatures, but the blue whale is sometimes over a hundred feet long, the largest known animal ever to exist on the face of the earth.

Animals are not only remarkable for their size. The flying fish is an example of an animal almost unique in its group. A thrust of its tail in the water, its fins spread like wings, and it is able to travel up to a quarter of a mile through the air. Other fish (*e.g.*, the mud-skipper) use their fins for walking !

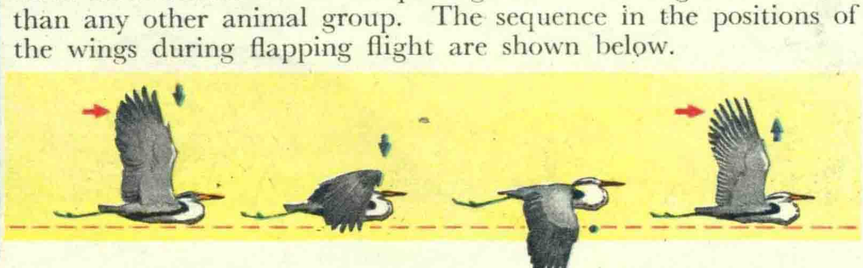


The sea anemone stands harmlessly on the sea floor. An inquisitive fish passes a little too close and is paralysed by the tentacles.



The ants rival ourselves in the complicated way in which they form social communities.

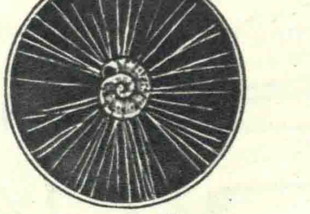
Birds have succeeded in conquering the air to a greater extent than any other animal group. The sequence in the positions of the wings during flapping flight are shown below.



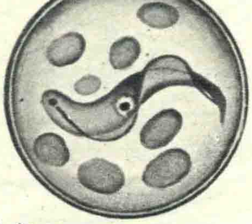
The Family of Animals

INVERTEBRATES

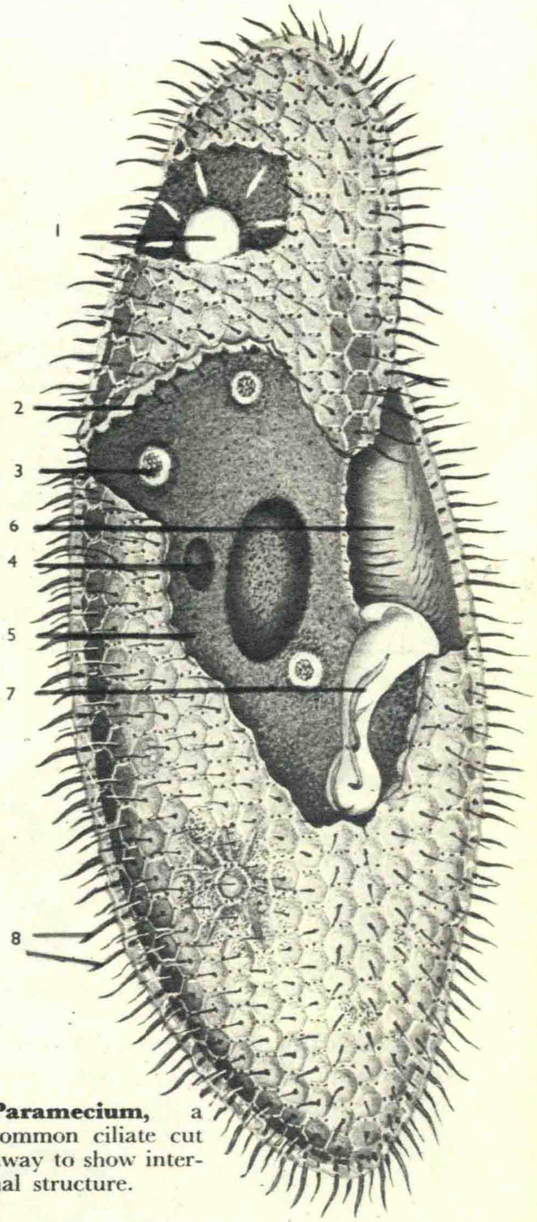
PROTOZOA. Microscopic animals whose bodies consist of one cell within which the vital functions are carried on. The group shows relatively more size variation than any other phylum. Locomotor organs (*e.g.* cilia) and mode of feeding help in classification.

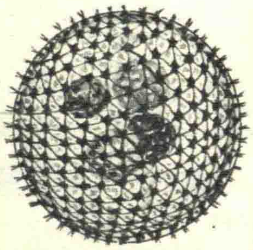


A foraminiferan, the shells of these forms sometimes occur in vast numbers forming deposits on the ocean floor.

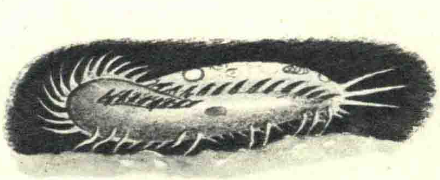


A trypanosome, one species of this parasite (*T. gambiense*) causes the terrible tropical disease, sleeping sickness.

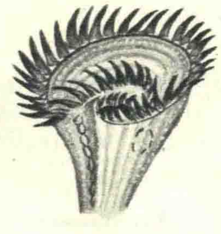




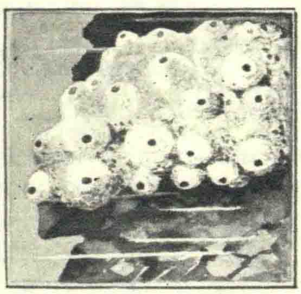
Volvox, a small green plant-like form, consists of hundreds of flagellates forming a swimming colony.

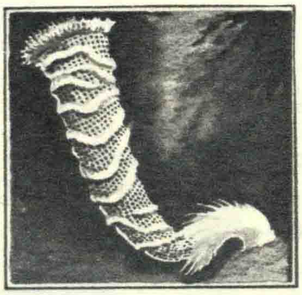


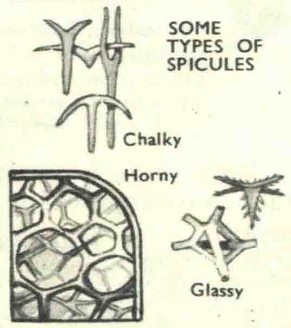
Stylonichia, a large ciliate, with many cilia on its undersurface fused to form thorn-like cirri used mainly for crawling.



Stentor, a large trumpet-shaped ciliate. Some cilia form membranelles which collect food.







Paramecium, a common ciliate cut away to show internal structure.

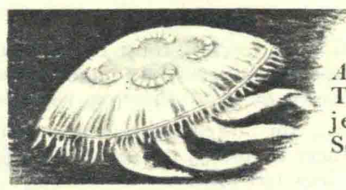
1. CONTRACTILE VACUOLE 2. PELLICLE
3. FOOD VACUOLE 4. SMALL NUCLEUS
5. LARGE NUCLEUS 6. ORAL GROOVE
7. FOOD IN GULLET 8. CILIA

Porifera (Sponges). Many-celled water animals. Two-layered porous body wall, round a hollow cavity. Have a chalky, glassy or horny skeleton.

Left, *Crumb o' Bread* sponge—a chalky form. Above, *Venus' flower basket*—a glass sponge.

Sponge classification is based primarily on the type of skeleton. (Above) The three main types.

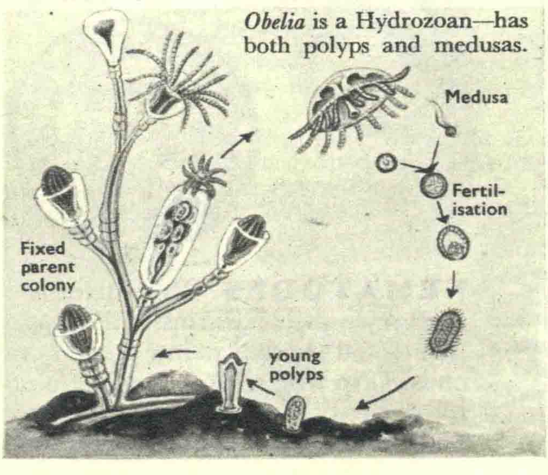
Coelenterates. Many-celled animals with a body wall of two layers enclosing a digestive cavity (enteron). Between is a layer of jelly (mesogloea). The inner cell layer (endoderm) is specialised for digestion and absorption, characteristic of the Metazoa (see Glossary).

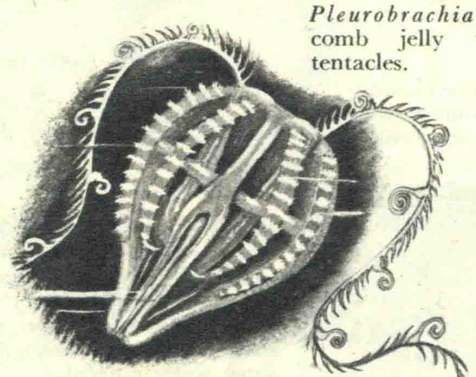


Aurelia. The common jellyfish, a Scyphozoan.

Ctenophora. A group distinct from other coelenterates in lacking stinging cells (nematocysts) and swimming by means of cilia arranged in combs.

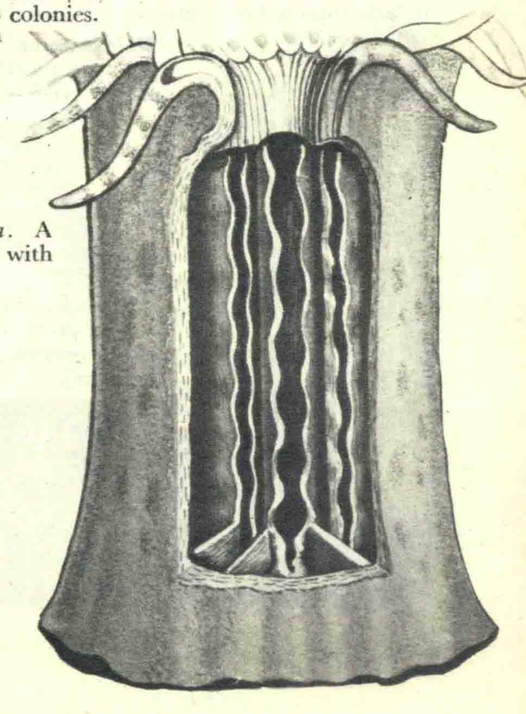
Obelia is a Hydrozoan—has both polyps and medusas.

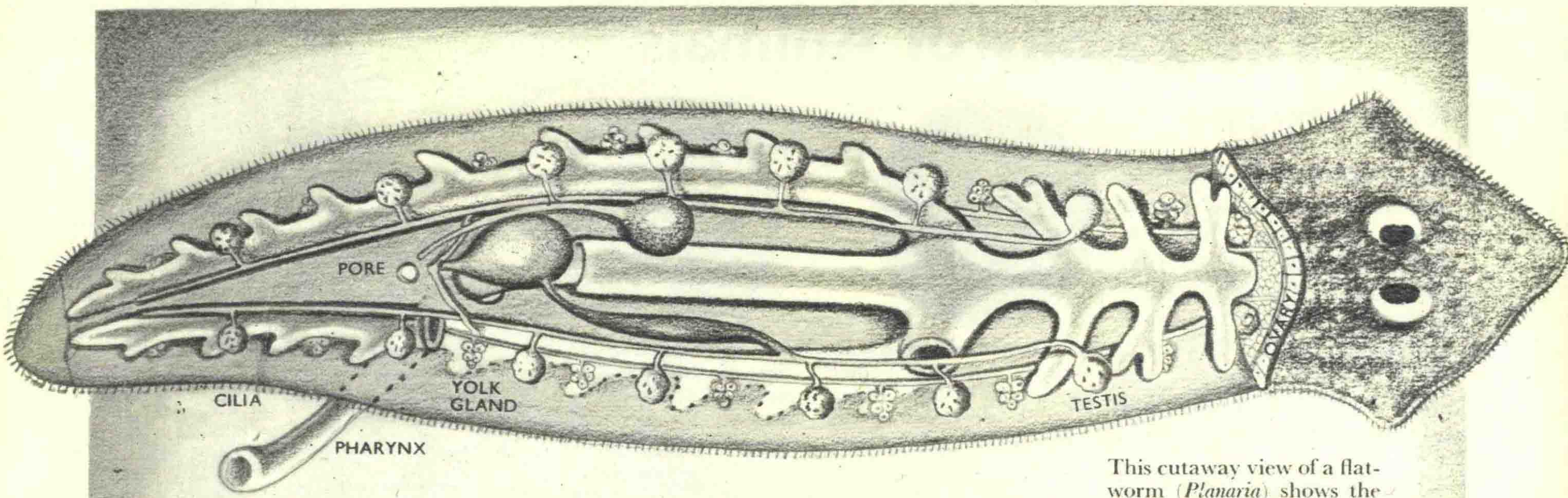




Pleurobrachia. A comb jelly with tentacles.

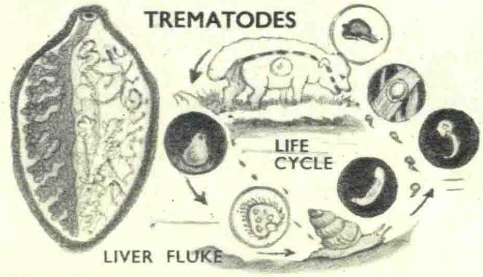
The Sea Anemone (below) is typical of the Anthozoa. Its enteron is divided by eight partitions (some forms have 6 or a multiple) The related corals live in colonies.





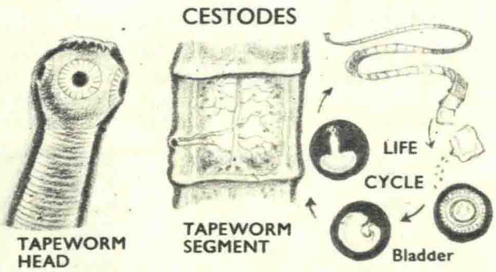
This cutaway view of a flat-worm (*Planaria*) shows the gut and reproductive systems. A small creature, it is common in streams. Note the cilia.

PLATYHELMINTHES (the flat worms). Usually small, flattened animals with a three-layered body. The gut has one opening, the mouth. Free living or parasitic.

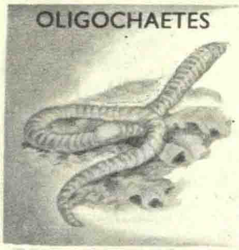


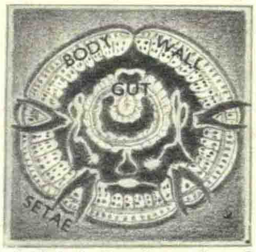
Trematodes (Flukes), Parasitic flatworms lacking cilia, with a tough cuticle and suckers with which they hang on to their host. Some have a complex life cycle.

Cestodes (Tapeworms), Internal parasites with no gut. Ribbon-like in form and made up of many segments (proglottides). May reach 60 ft. long.

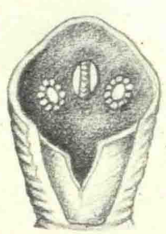


ANNELIDS (Segmented Worms). Body three layered; the middle layer being muscular, and divided into segments. True body cavity (coelom) between the gut (a straight tube with two openings) and body wall.

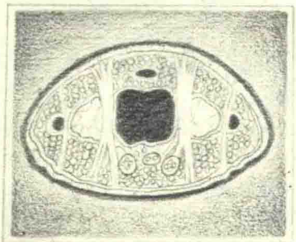




(Left) An earthworm. (Right) Section of an earthworm showing the outer epidermis, a middle muscle layer, and the "U" shaped gut.

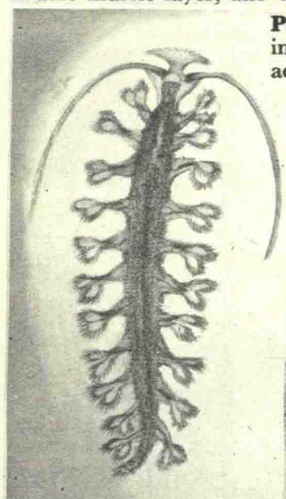


(Left). A leech (group Hirudinea). Most leeches are partly parasitic, sucking blood from their hosts. (Right) Cutaway of head showing wound-inflicting teeth.

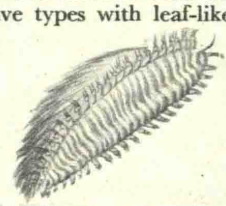


Section through a leech. Central area is gut, rest is mostly muscle.

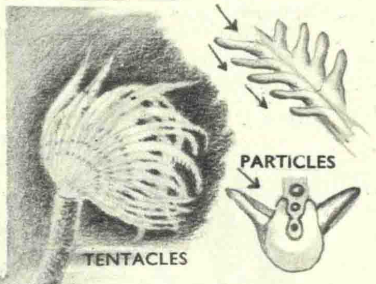
Polychaetes (Bristle worms), the largest Annelid group including tube dwellers with feathery tentacles, burrowing forms, and active types with leaf-like legs (parapodia).

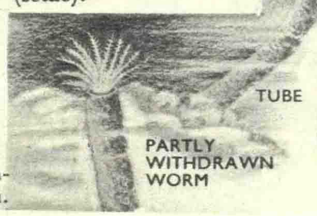


Tomopteris, an active swimmer with leaf-like parapodia.

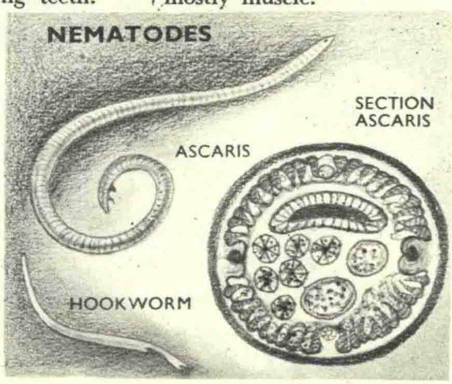


Aphrodite, the sea mouse, seen from underneath, is covered in bristles (setae).



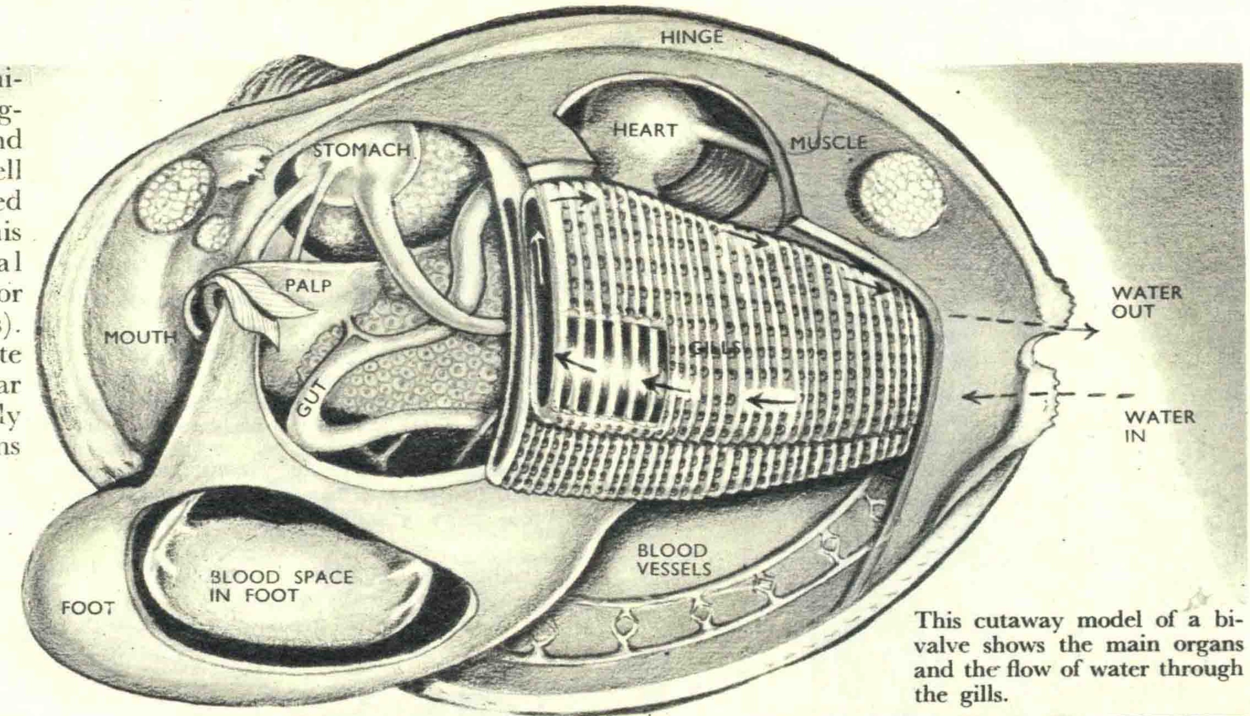


Sabella is a tubeworm with long feathery tentacles used to trap small food particles. Diagrams show a tentacle (above) and a section (below). The groove sorts particles by size. Arrows show water current.

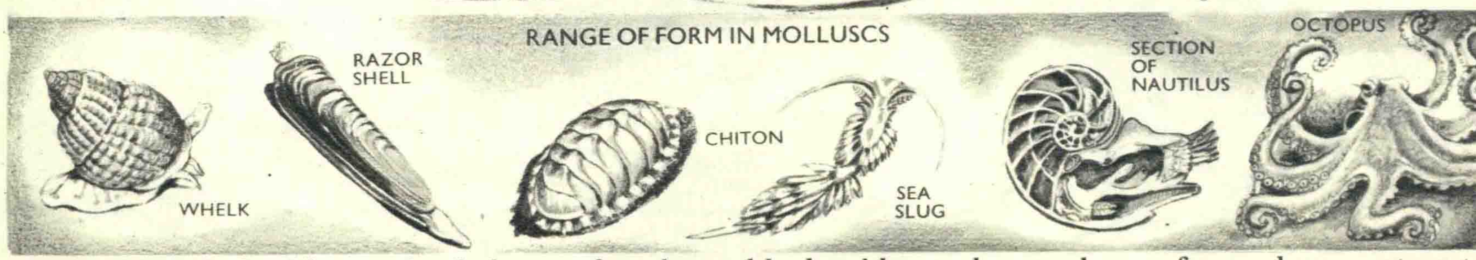


NEMATODES (Roundworms). Long cylindrical worms with an unsegmented body, pointed at both ends. No true coelom. Have fluid filled cavity between gut and outer body wall. Some occur free in soil.

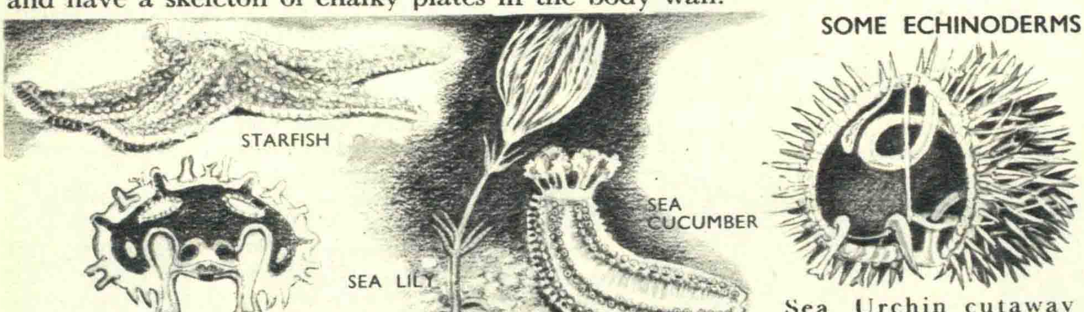
MOLLUSCS. Animals with soft unsegmented bodies and usually having a shell of lime salts secreted by the mantle. This may be external (*e.g.*, bivalves) or internal (*e.g.*, slugs). They have a definite head, a muscular foot, and usually breathe by means of gills.



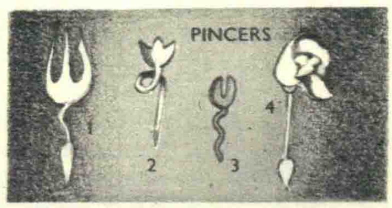
This cutaway model of a bivalve shows the main organs and the flow of water through the gills.



ECHINODERMS. These animals have a three-layered body with a coelom made up of several compartments and each performing a separate function. Adults show radial symmetry (see Glossary), are usually 5-rayed and have a skeleton of chalky plates in the body wall.

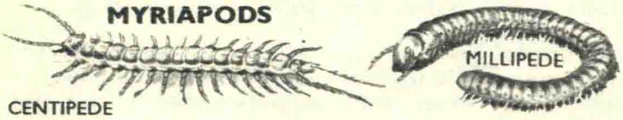


Sea Urchin cutaway model showing structure.



Some Echinoderms have pincers (pedicellariae) on their skin. These protect and keep the skin clean. 1, tridactyle. 2, trifoliate. 3, ophiocephalus. 4, gemmiform.

ARTHROPODS. These are segmented animals, and usually each segment bears jointed limbs (at least one pair modified as jaws). Nervous system, same plan as Annelids, head ganglia with a ventral cord of paired ganglia.



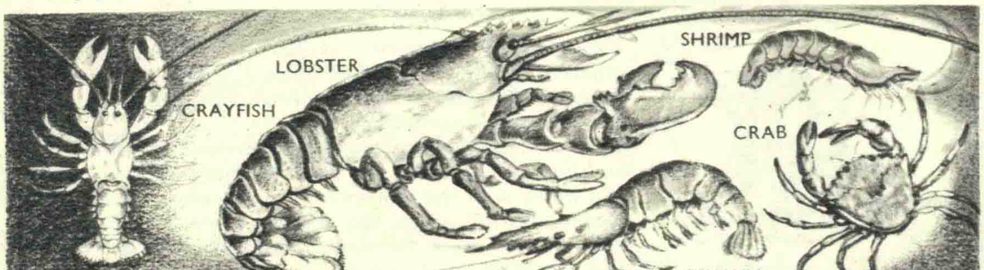
Myriapods (Centipedes and Millipedes). Arthropods with long bodies, many leg-bearing segments and a distinct head. Like insects breathe by means of air tubes (tracheae).

Crustacea. Mainly aquatic, breathe by gills; two pairs of antennae. A varied group containing the crabs, lobsters, crayfishes, shrimps, etc.

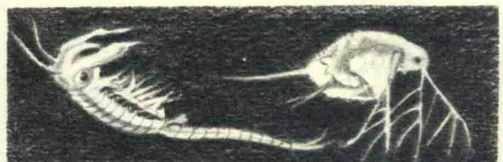
Isopods. No carapace, body flattened *e.g.*, *Asellus*, *Ligia*.

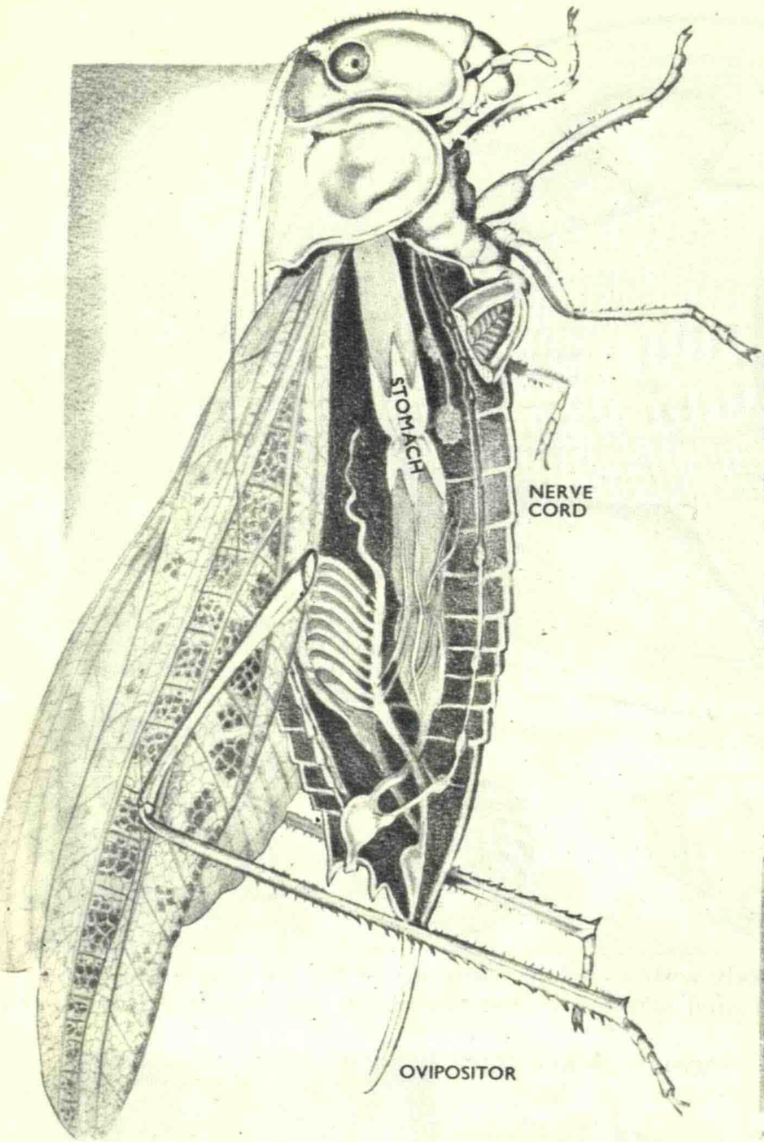
Amphipods. No carapace, body flattened laterally, *e.g.*, *Gammarus*.

Decapods Carapace (breastplate) covers the thorax. The abdomen (hind region) may be long (*e.g.*, crayfish), or folded under the body (*e.g.*, crabs). A very varied group with forms on land, in freshwater, and in the sea. A giant crab may measure 12 ft. across.

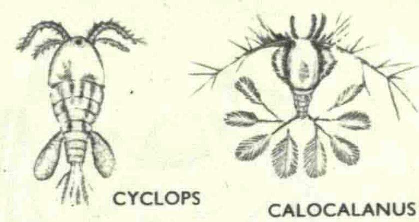


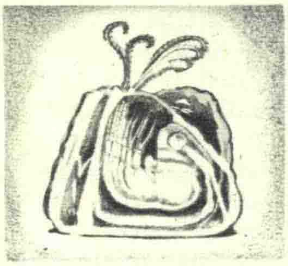
Branchiopods. Free living forms with flattened limbs which are fringed with hairs. Below, left: *Chirocephalus*, right: *Daphnia.*





This cutaway model shows the structure of the grasshopper, which is similar to that of most insects. Note the ventral (lower side) nerve cord which is characteristic of most invertebrates with nervous systems.



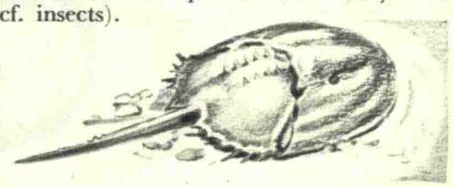


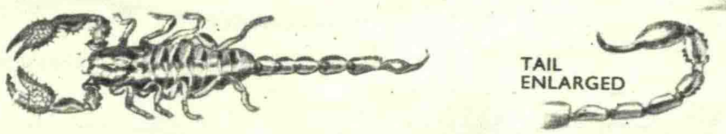
Copepods. Free-living or parasitic Crustacea lacking a carapace. Often have enlarged antennules used for swimming. Form a large part of the plankton.

Cirripedes (barnacles). Have reduced head and abdomen, have a shell and may be stalked.

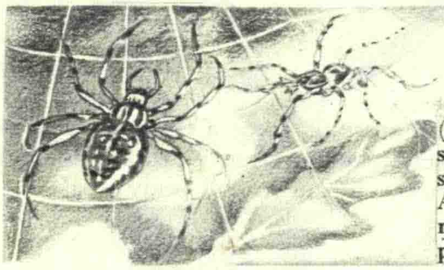
Arachnids (spiders, scorpions, mites, King Crabs). Body divided into two parts, a front prosoma and a rear opisthosoma. They have four pairs of walking legs (cf. insects).

(right) *Limulus*, The King Crab, is not really a crab, it is a primitive arachnid which lives in the sea.



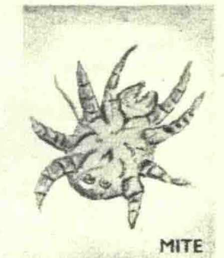


A scorpion holds prey in its pincers, kills it with its tail sting.



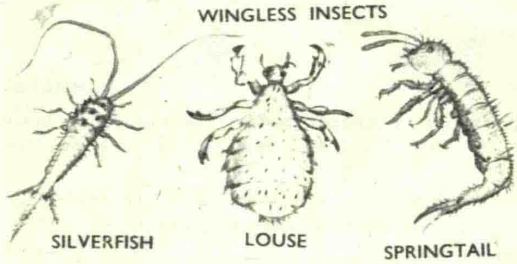
(left) A male and female garden spider. The male is usually smaller than the female. (above) A spider's poison fangs underneath the head are used to kill prey.

The harvest-men have very long legs and belong to a group of arachnids called phalangids. They feed on insects and other small arthropods. Mites are usually minute arachnids, many less than ⅛-inch long. Some are parasitic on animals.

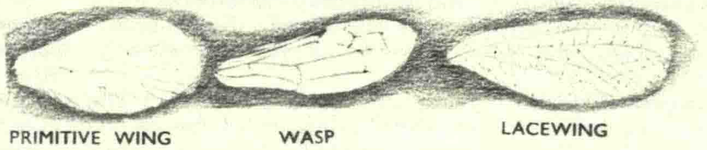


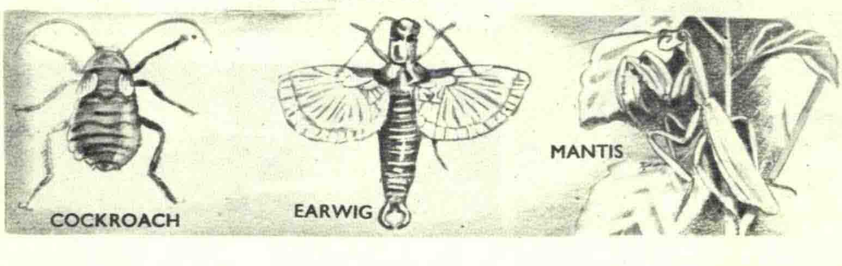
The Insect World

INSECTS are arthropods with a tracheal (air tube) system for breathing. The body is divided into three regions, the head, thorax and abdomen. The head is very specialised, bears sense organs, and mouthparts used in food collection and sometimes defence. The thorax usually bears wings and three pairs of legs.



Classification. The insects are divided into two main groups, the apterygote and pterygote insects. Apterygota – primitive insects without wings, little metamorphosis (see page 39). Pterygota nearly always have wings and long metamorphosis. *Left* The silverfish and springtail are apterygotes, the louse is a pterygote form lacking wings.

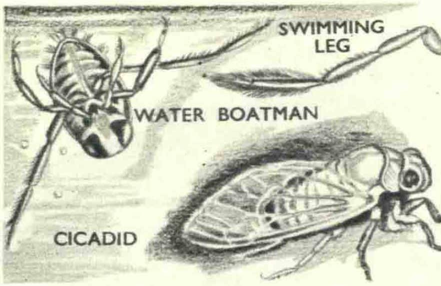


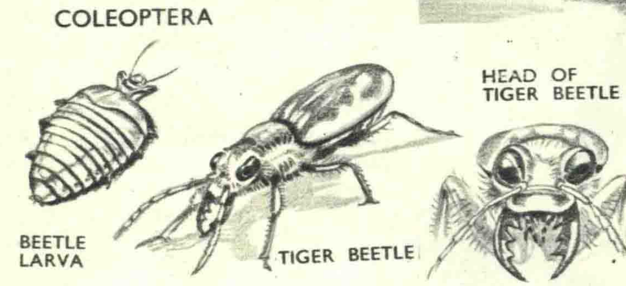


Though the cockroach, earwig, and mantid look very different, they are in fact related. This we know by studying their fossil forms, and also by comparing their present anatomy.

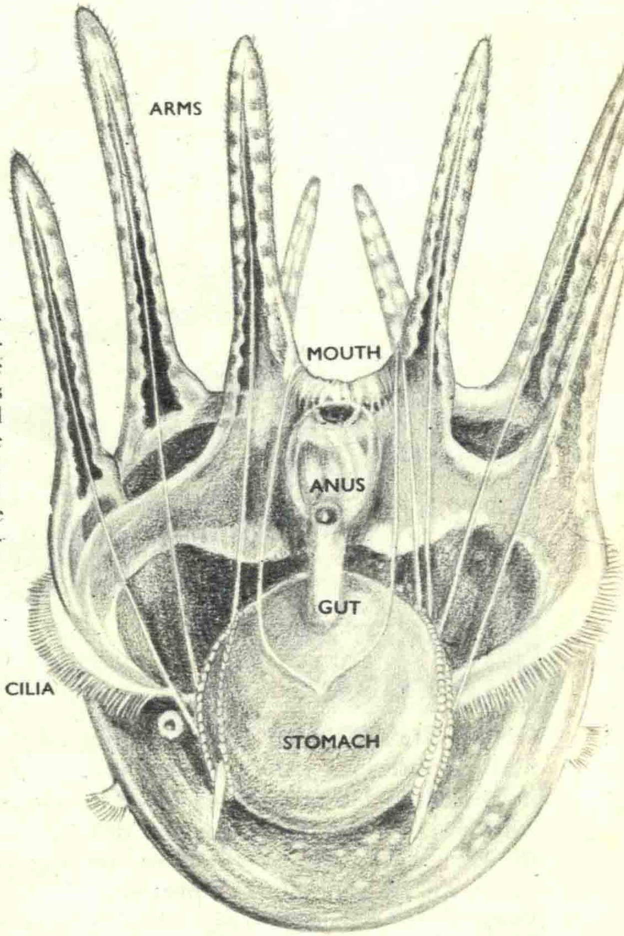
The cockroaches are common in Britain, living in warm buildings where there is a suitable supply of food. Their real home is in the tropics and sub-tropics. The earwigs are interesting since the female protects the hatched nymphs in the soil for some time. Mantids are tropical and use their forelimbs for catching prey.

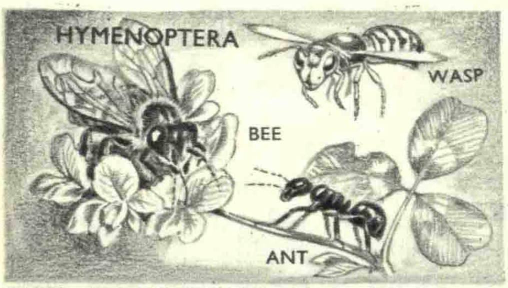
Hemiptera (Bugs). A large group which includes the greenfly and many other plant pests. The water boatman is a large form common in ponds. The cicadids are mainly found in warm regions. Some have a life history taking seventeen years. **Coleoptera** (Beetles). The largest insect group, occurring in every sort of situation. Many are pests (*e.g.*, Colorado beetle).

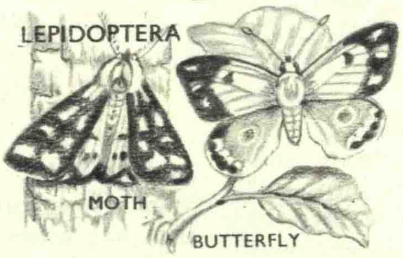


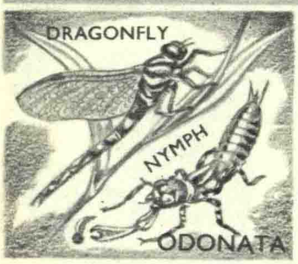


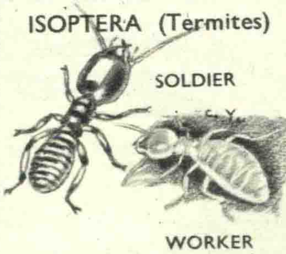
Below are five other insect groups. The Hymenoptera include the bees, ants, and wasps which form large social communities. With the flies (Diptera) and moths and butterflies (Lepidoptera) they are very important in pollinating flowers.

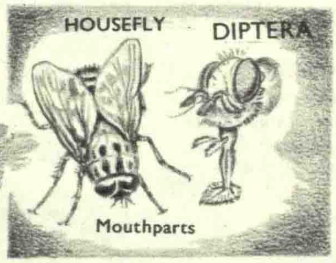






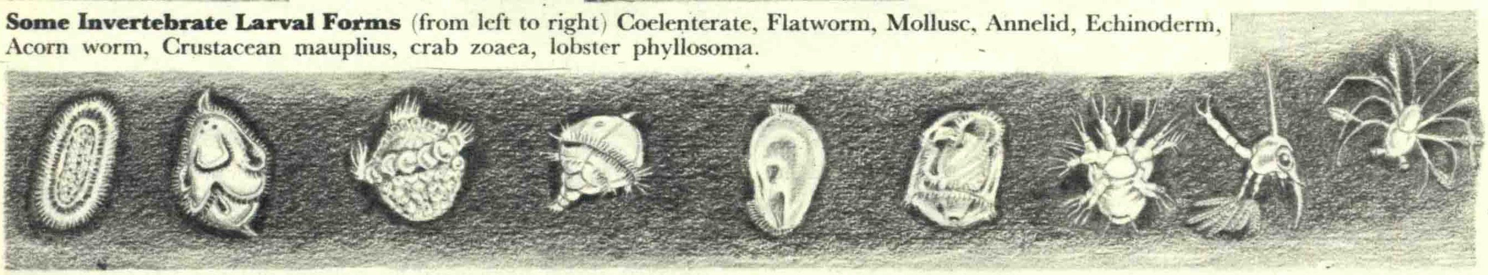




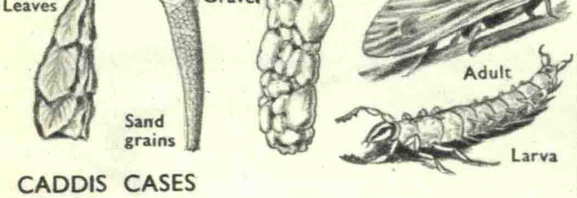


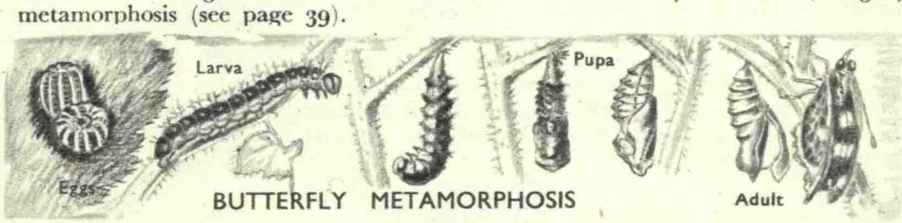
A much enlarged view of a developing sea urchin larva (pluteus). A delicate transparent creature with long arms supported by flimsy rods of lime, it swims actively at the sea surface gradually changing into the prickly adult sea urchin.

Some Invertebrate Larval Forms (from left to right) Coelenterate, Flatworm, Mollusc, Annelid, Echinoderm, Acorn worm, Crustacean mauplius, crab zoaea, lobster phyllosoma.



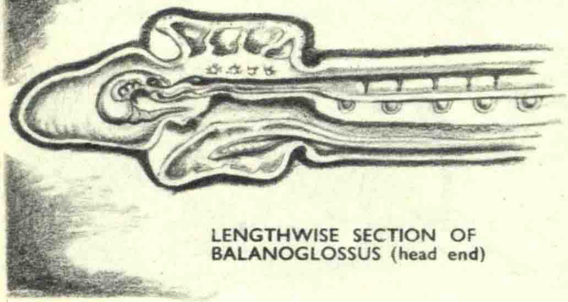
Insect larvae. Caddis larvae live in freshwater and often build portable protective cases to live in. They grow into pupae after a time and emerge from the water as adults. The butterfly has a slow, lengthy metamorphosis (see page 39).

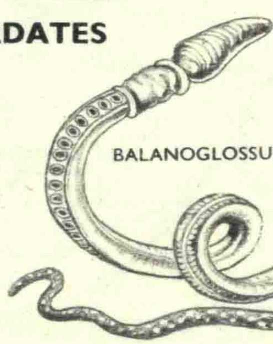


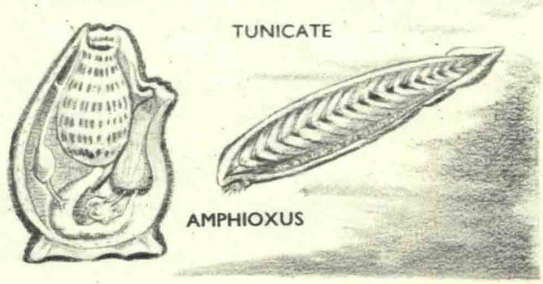


INVERTEBRATE CHORDATES

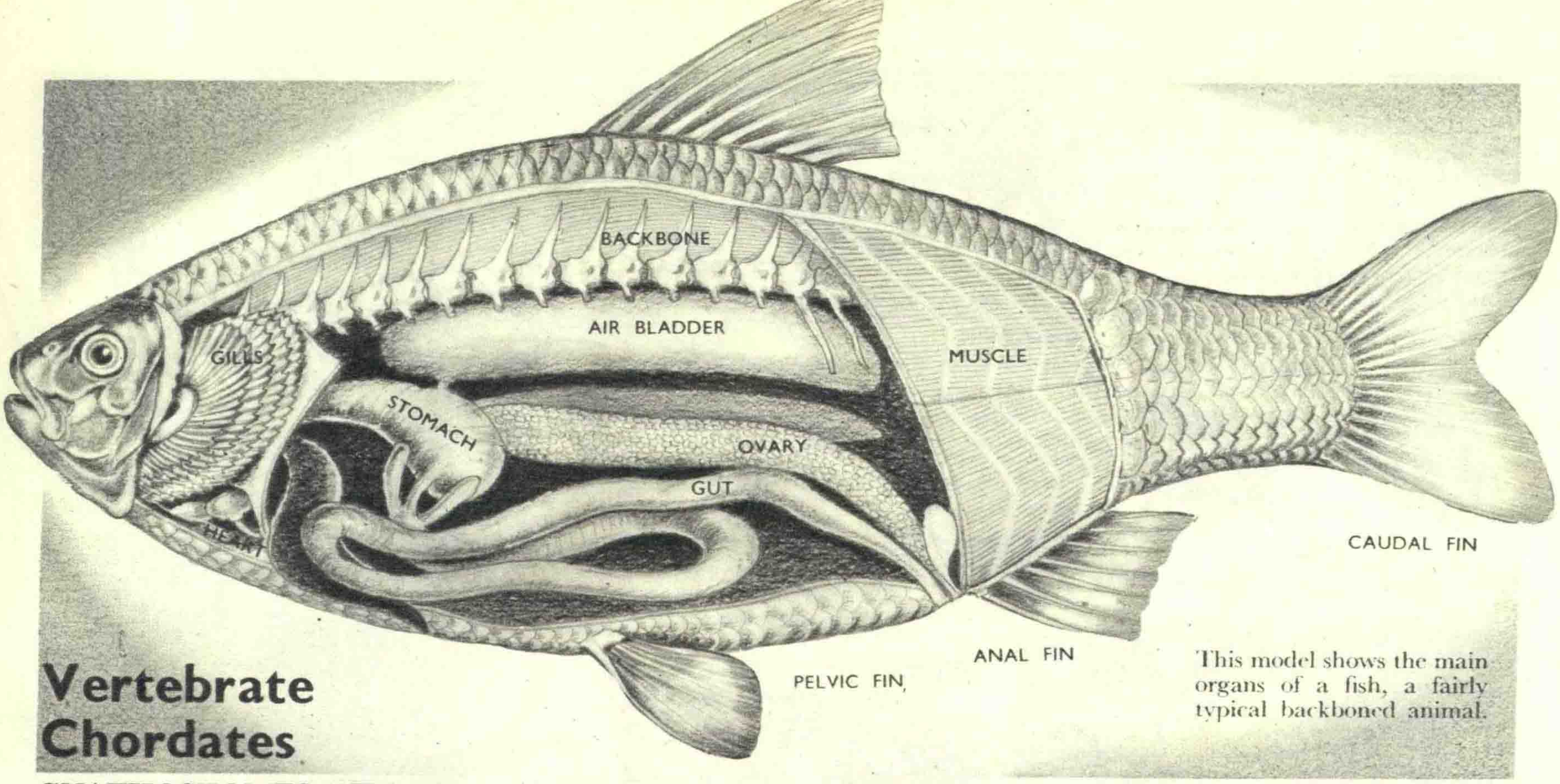
Animals with no vertebral column, but a notochord (see Glossary) at some stage in life.







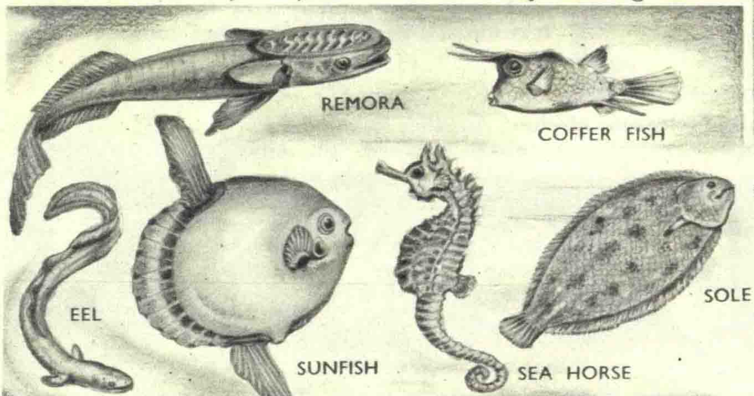
Vertebrate Chordates



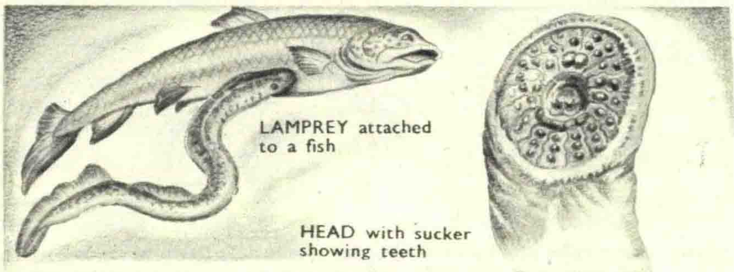
This model shows the main organs of a fish, a fairly typical backboned animal.

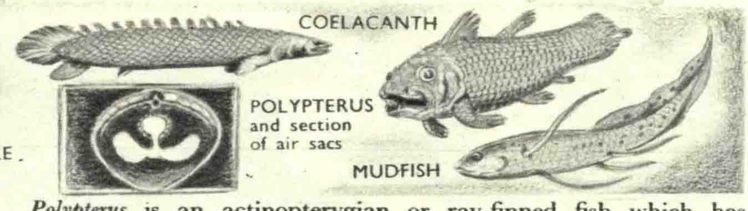
GNATHOSTOMES. This group of vertebrate animals includes the fishes, amphibians, reptiles, birds and mammals. These animals have important features in common. They have jaws, a definite brain enclosed in a case (cranium) of bone or cartilage. Paired limbs are nearly always present.

Bony Fishes (Actinopterygii). This is the largest fish group. They have invaded every corner of the sea in their search for new homes, and include some of the world's most beautifully coloured animals. (below) A few of the many differing kinds.



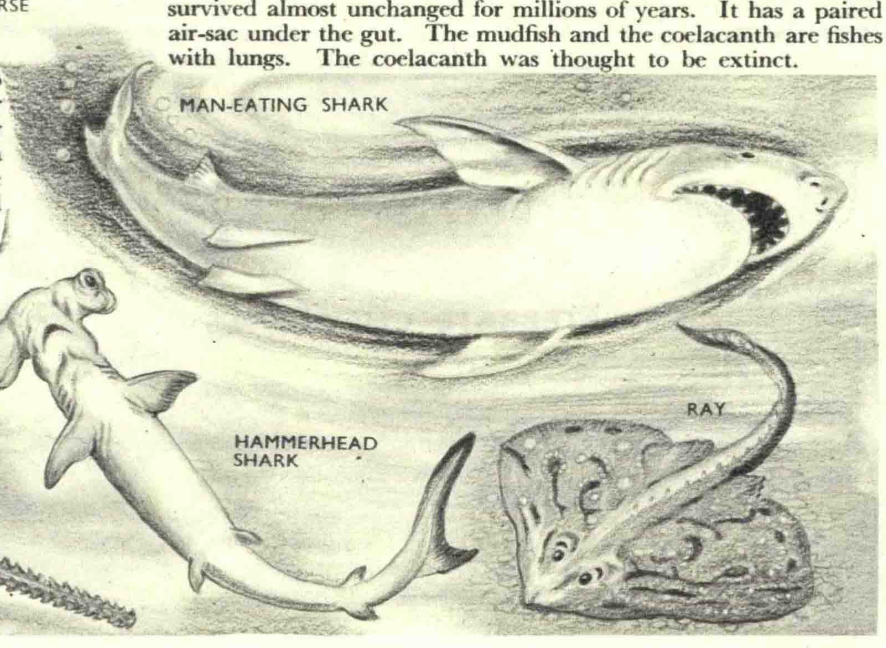
AGNATHA. (The jawless vertebrates). This is a small group only represented today by the lampreys and hag-fishes. These are eel-like animals. The lampreys use their rasping sucker to grasp their prey.

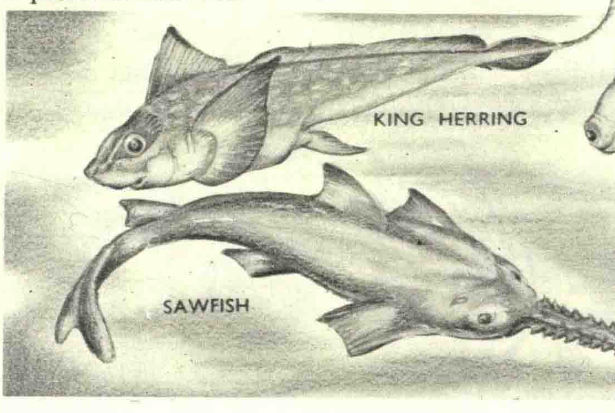




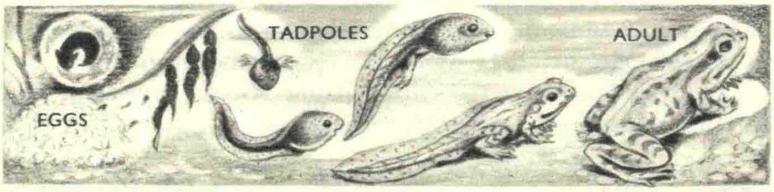
Polypterus is an actinopterygian or ray-finned fish which has survived almost unchanged for millions of years. It has a paired air-sac under the gut. The mudfish and the coelacanth are fishes with lungs. The coelacanth was thought to be extinct.

Cartilage Fishes (Elasmobranchs). This large group of fishes includes the sharks, skates and rays. A peculiar feature is the complete absence of bone, cartilage only being present in the skeleton. Some sharks reach a length of thirty-five feet. The king herring, a cartilage fish in a distinct group (Bradyodonts), has large eyes and a parrot-like mouth.

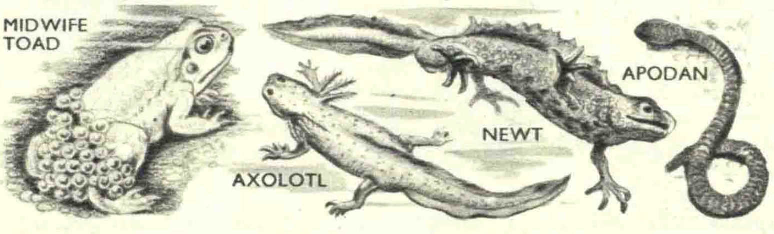




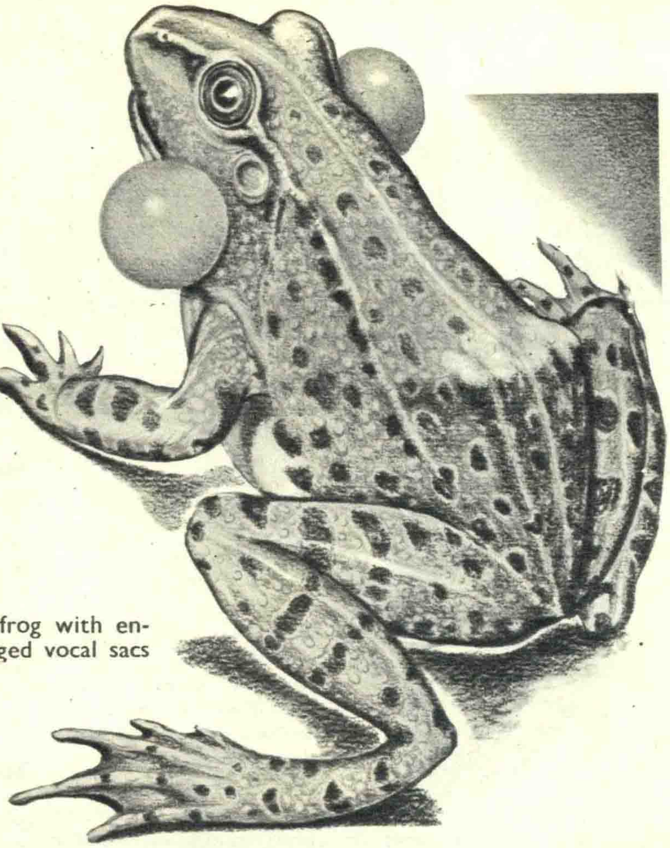
AMPHIBIANS. Animals which usually need to return to the water to breed, are cold blooded, and, except in some limbless forms (Apoda), lack scales. Amphibians are unable to live in salt water, have a moist skin through which they can "breathe," and usually also have lungs.



The development of the frog is similar to that of many amphibians. Eggs laid in the water, develop into gill breathing tadpoles. Lungs are developed later making life on land possible.

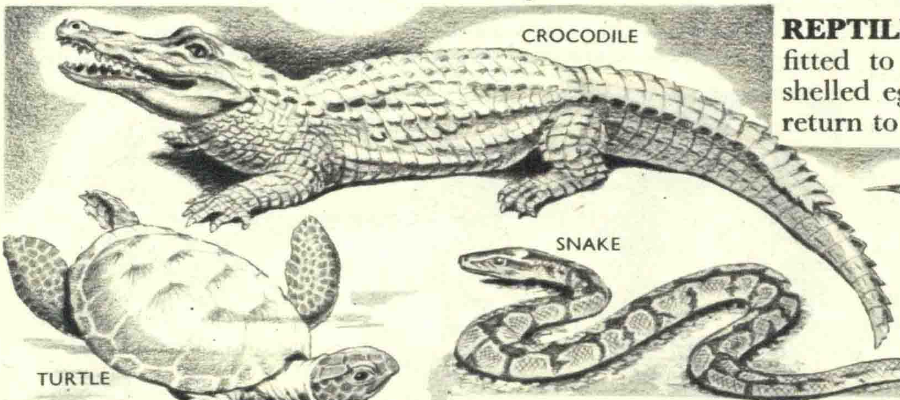


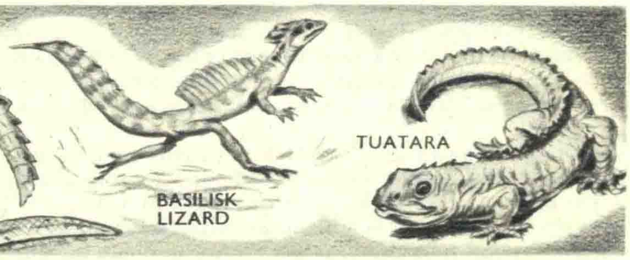
The male midwife toad carries the eggs between his back legs. Apodans are wormlike burrowing forms which have no legs.



A frog with enlarged vocal sacs

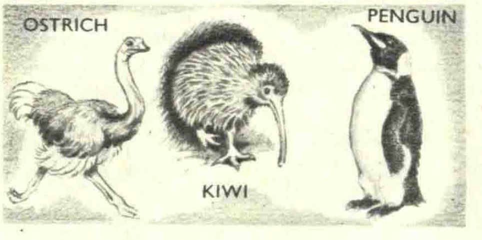
REPTILES are cold blooded animals completely fitted to life on land. They have lungs and lay shelled eggs. Even the turtles which live in the sea return to lay their eggs on land. The skin has scales.

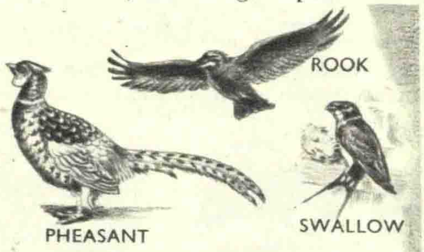


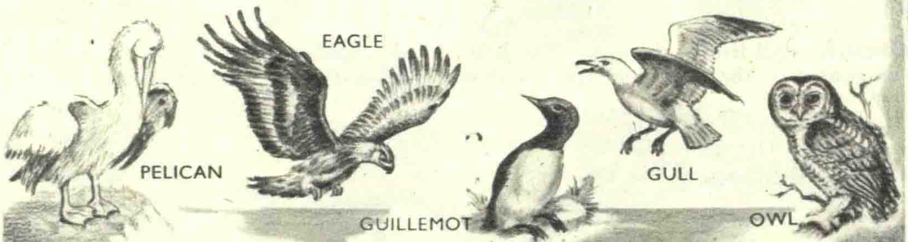


BIRDS (Aves) are often called "glorified reptiles" because they show many similarities to the reptiles – and probably evolved from a group of reptiles. Scales occur on the legs and feet, and they lay shelled eggs. Their most notable feature is the presence of feathers. The forelimbs are modified as wings, some of the wing feathers being very long to aid flying.

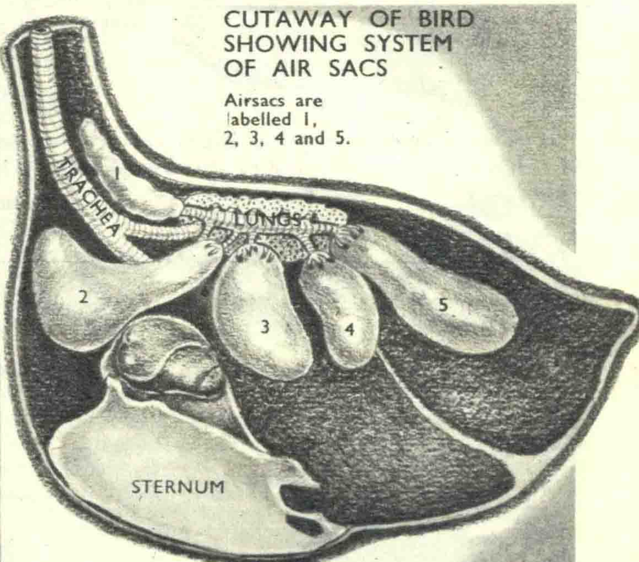
Some birds such as the ostrich, kiwi and penguin, have lost the power of flight. The penguins have their wings reduced to swimming flippers. Birds show many specialist features in beak shapes, arrangement of toes, and wing shapes.





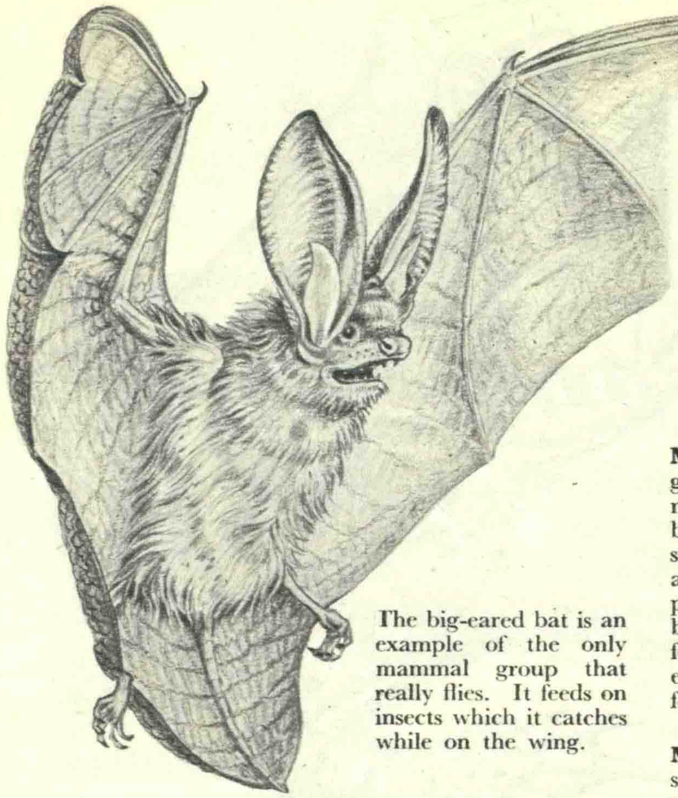


The pheasant is a game bird (galliformes), and the rook and swallow members of the largest bird group, the perching birds (passeriformes). The pelican (pelecaniformes), eagle (falconiformes), guillemot and gull (charadriiformes), and the owl (strigiformes) are representatives of a few of the many other bird groups.



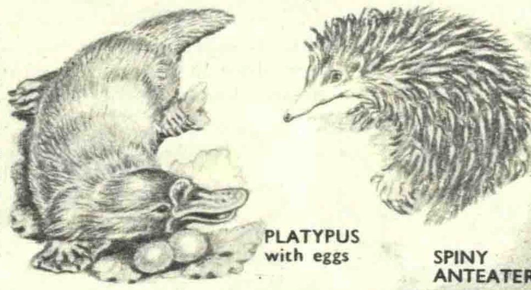
Birds have a system of air-sacs which help the lungs to supply the large amount of oxygen required to provide the energy for flying.

MAMMALS. The most highly developed animals, and with the birds are the most successful land animals. Their most characteristic feature is the development of hair which in most mammals covers the whole of the body. This helps to maintain a high body temperature (the mammals and the birds are the only warm-blooded animals). They nourish their young with milk which is produced by special milk (mammary) glands, and, except in the Monotremes which lay eggs, the young are born alive. Another feature is the care of their young, and their high intelligence compared with other animals.

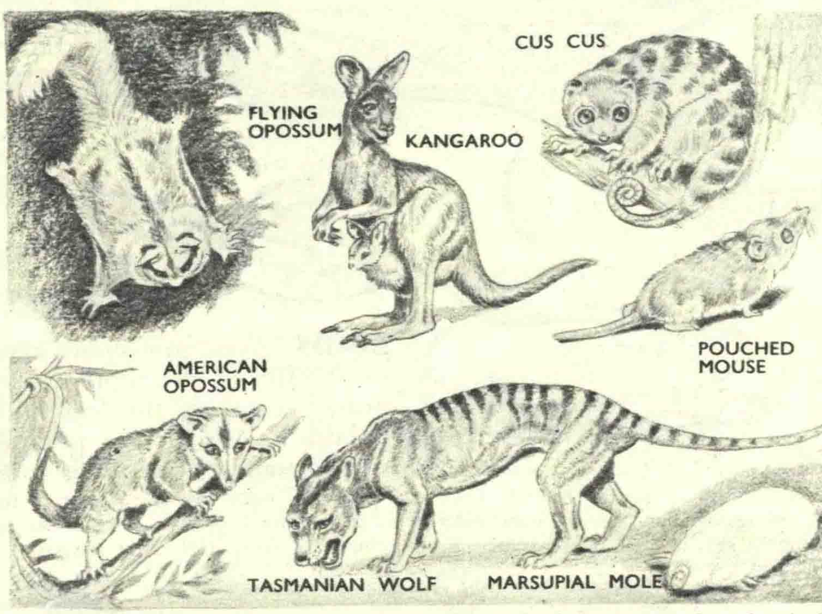


The big-eared bat is an example of the only mammal group that really flies. It feeds on insects which it catches while on the wing.

Monotremes. This small group of egg-laying mammals contains the duck-billed platypus and the spiny ant-eater. Neither animal has teeth. The platypus has a duck-like beak with which it "fishes" for molluscs, and the ant-eater has a "beak" adapted for eating ants.

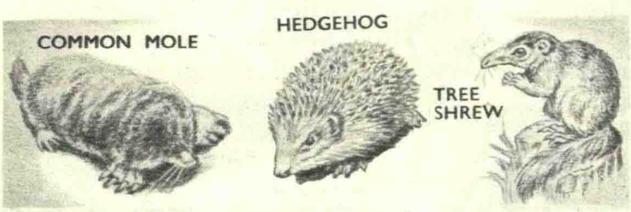


Marsupials (The pouched mammals). They bear their young alive but in a small and relatively unformed state. The female has a pouch on the lower part of the abdomen in which the young are carried and suckled until they are able to fend for themselves. The Marsupial group has many similar animal types to the placental mammals; for example, the flying opossum and flying squirrel, the marsupial mole and common mole can be compared.

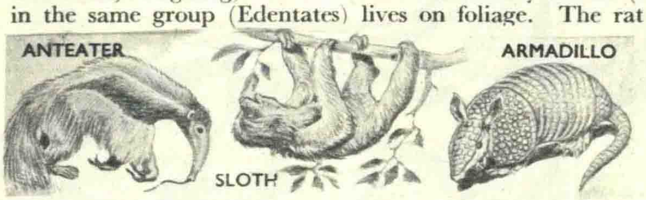


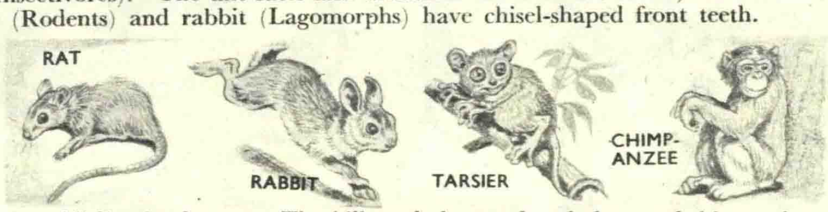
Placentals are the most advanced mammals. Their name is derived from the fact that during the development of the young animal (embryo) it is actually connected to the mother by means of a wedge of tissue called the placenta. This supplies food, oxygen, and chemicals to the embryo, and also removes waste substances. This means that the young are born at a more advanced stage than the marsupial young, for example. They feed on milk from the mother for some time after birth. The brain has a large cerebrum (see page 109) and its great development accounts for the complicated behaviour of these animals.

The groups of placental mammals are many and varied. They are found all over the world, from the freezing wastes of the arctic to the deserts of Africa, Asia and America, from sea level to great heights in the Himalayas, in fresh-water lakes and rivers and the sea. They not only include ourselves, the highest mammals, but also the whales which include the largest animals ever to exist on the earth.

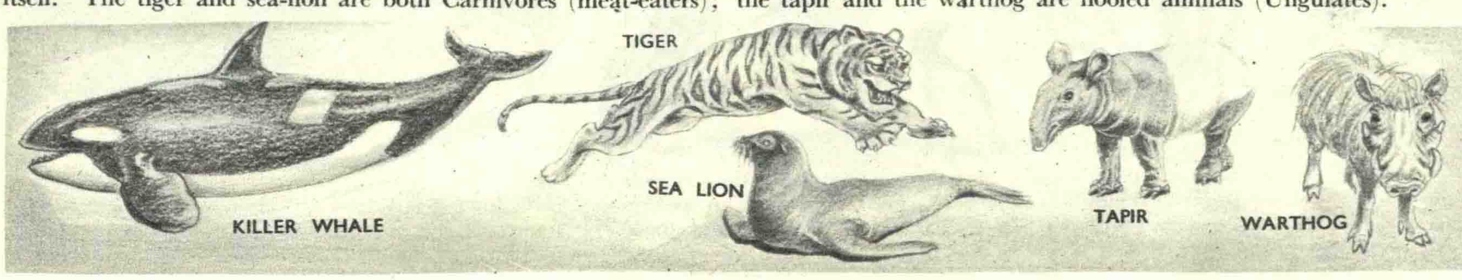


The mole, hedgehog, and tree shrew eat mainly insects (Insectivores). The ant-eater and armadillo are both ant-eaters, but the sloth in the same group (Edentates) lives on foliage. The rat (Rodents) and rabbit (Lagomorphs) have chisel-shaped front teeth.





The whales with the dolphins and porpoises form the Cetacea. All live in the sea. The killer whale attacks whales much bigger than itself. The tiger and sea-lion are both Carnivores (meat-eaters); the tapir and the warthog are hoofed animals (Ungulates).

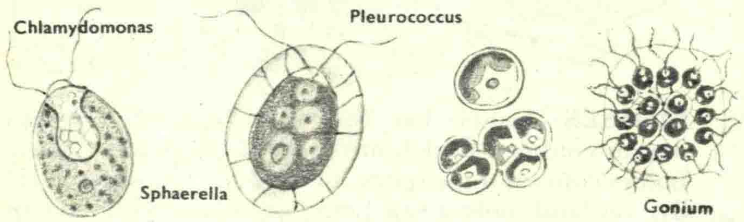


The Family of Plants

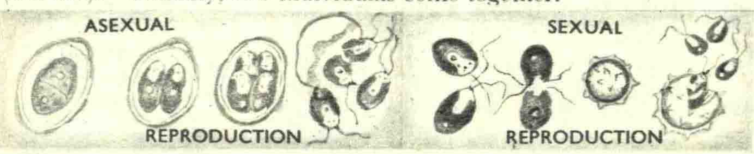
Plants can be divided into three main groups, the **Thallophyta** which include the Algae, Bacteria and Fungi; the **Archegonitae** which include the Liverworts, Mosses and Ferns, and the **Spermaphyta** (pines and flowering plants).

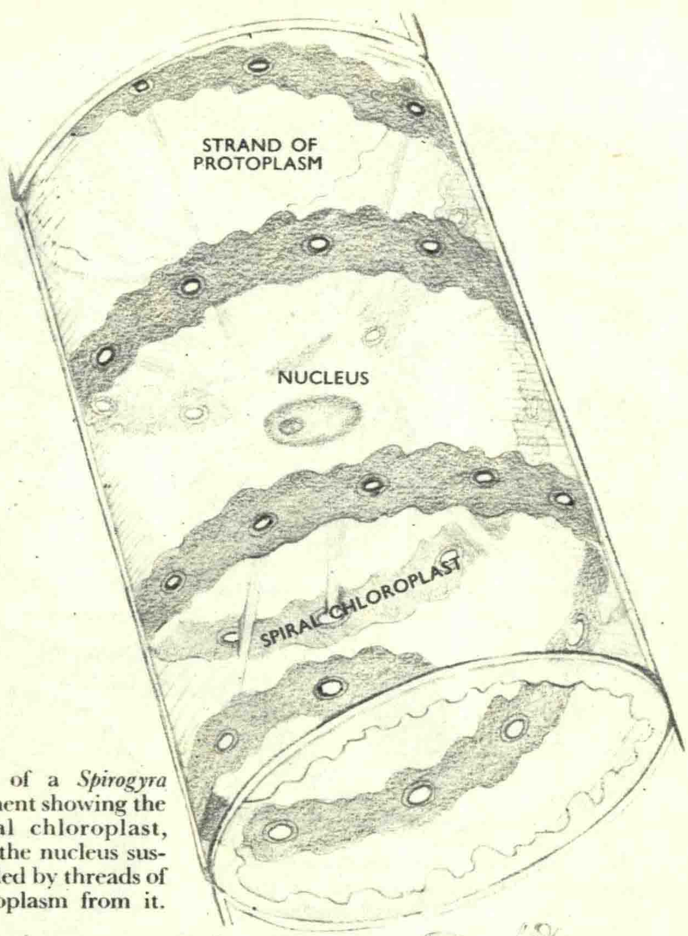
ALGAE. Plants which usually live in water. Many of the simple forms are one-celled or have a many-celled thallus (see Glossary). All Algae have chlorophyll though this may be masked by pigments which are usually red, brown, or blue.

Simple forms – the single-celled types such as *Chlamydomonas* and *Sphaerella*, though some form colonies (*e.g., Gonium*). These all have flagella, but *Pleurococcus* commonly found on tree trunks does not.



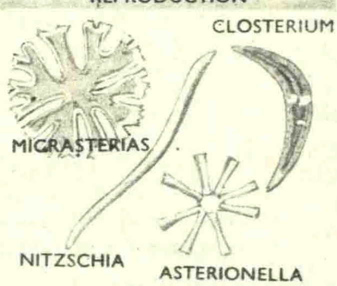
Chlamydomonas, on reaching a certain size stops moving, takes in its flagella and divides into 2, 4 or 8 new individuals which are released (asexual). Sexually, two individuals come together.

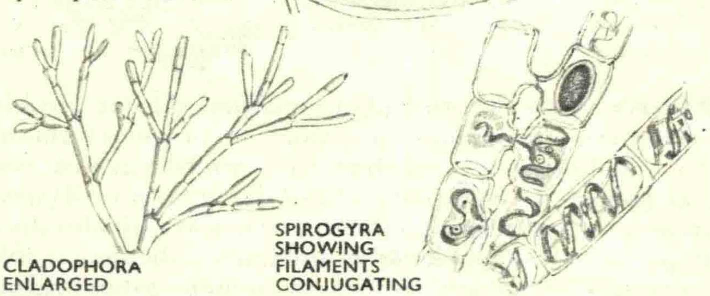




Cell of a *Spirogyra* filament showing the spiral chloroplast, and the nucleus suspended by threads of protoplasm from it.

Diatoms and Desmids are mostly one-celled plants which live in water. Diatoms are very plentiful in the sea and fresh water forming a large part of the plankton (see Glossary). They have a shell of two halves which fit one inside the other. The Desmid cell consists of two equal halves often separated by a constriction, where the nucleus is.

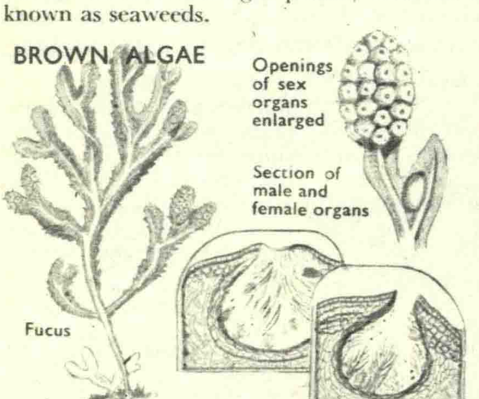


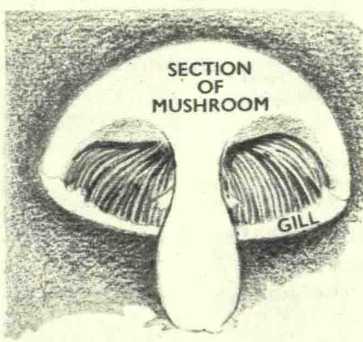


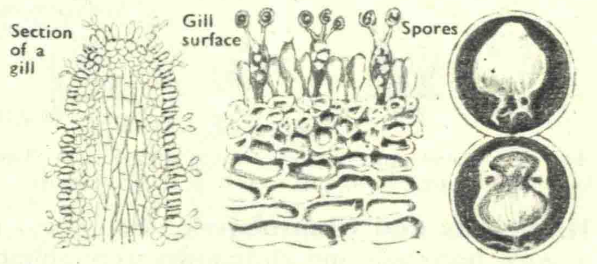
Green Algae owe their coloration to chlorophyll and several pigments. *Spirogyra* is the simplest type of many-celled green alga. It is a ribbon-like thread (filament). *Cladophora* is made up of branched filaments.

Brown and Red Algae. The Brown algae have a brown pigment which masks the chlorophyll and gives them their brown colour. They are the largest and most advanced algae, often reaching lengths of several hundred feet. Red algae have a red pigment, and are often small fragile plants; with the brown algae are better known as seaweeds.

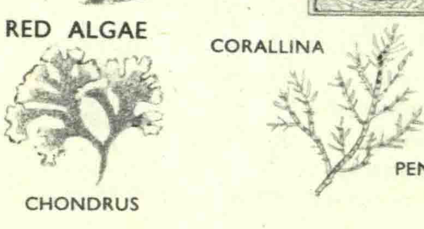
FUNGI are plants which have no chlorophyll. They depend on organic material which has been made by other plants and animals. Many are parasites while others (saprophytes) live on dead material.

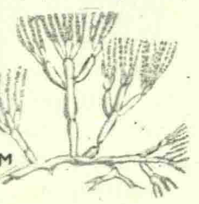


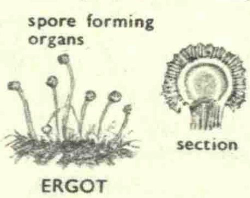


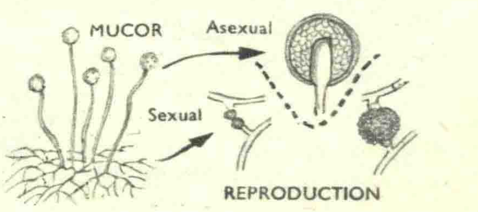


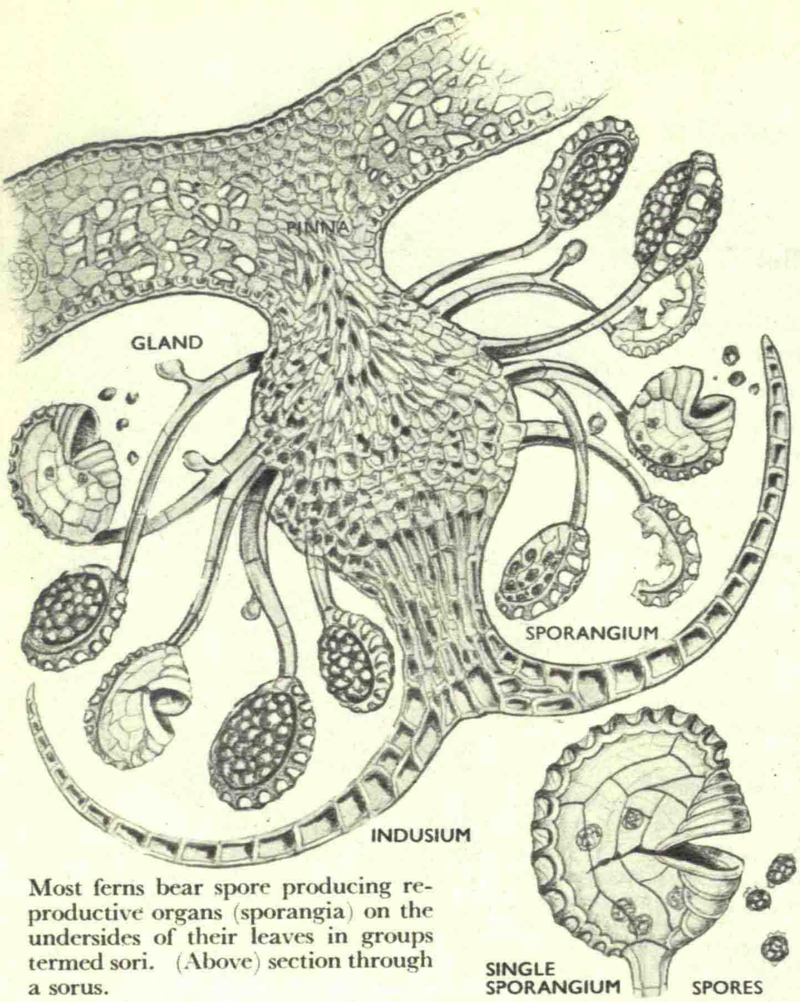
Basidiomycetes are fungi with no sexual organs. They reproduce by means of powdery spores. Familiar examples are the mushrooms and toadstools. **Ascomycetes** usually lack sexual organs; spores are produced in bodies known as asci (*e.g., Penicillium* and Ergot of rye). **Phycomycetes** reproduce sexually and by spores (*e.g., Mucor*).





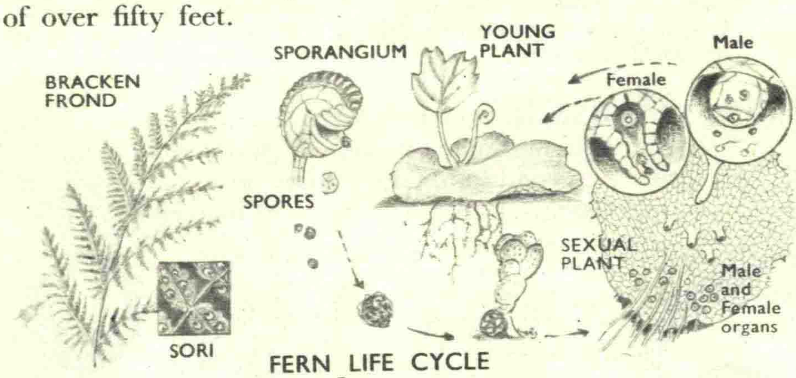






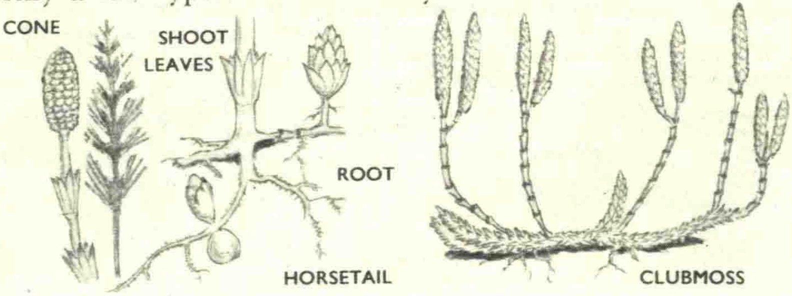
Most ferns bear spore producing reproductive organs (sporangia) on the undersides of their leaves in groups termed sori. (Above) section through a sorus.

FERNS. Like the other plants mentioned so far, ferns have no flowers. They show an advance on previous forms however, in having a much better developed vascular system (see page 35). Most ferns live in damp places. Typically, ferns have large leaves (fronds) which are usually divided many times into smaller lobes (pinnae). The stem is usually weak and often takes the form of an underground rhizome. Most ferns are small, but some tree ferns reach a height of over fifty feet.

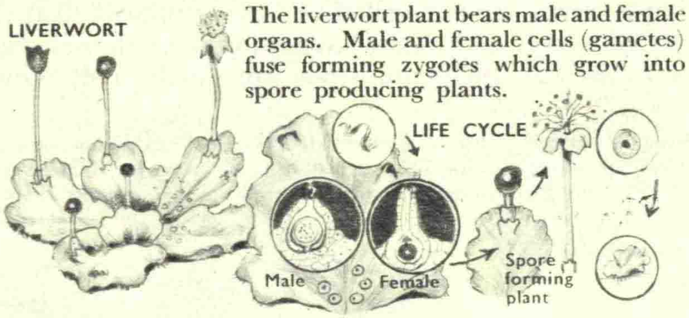


The ripe sporangium bursts releasing the spores. These develop into plate-like plants (prothalli) which bear sex organs.

Horsetails and Clubmosses. Some 250 million years ago the horsetails and clubmosses were abundant. Today only a few types remain. They are related to the ferns.

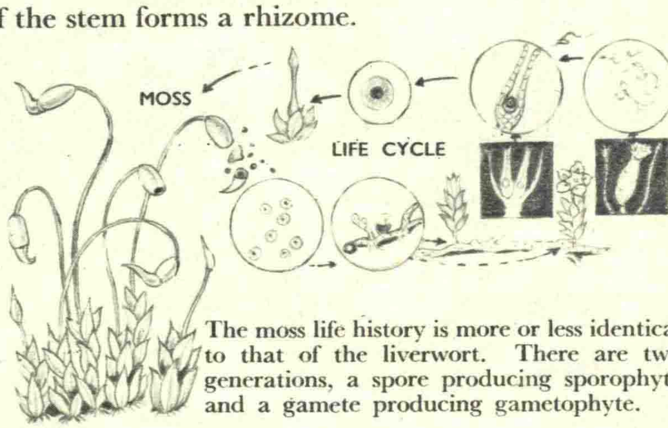


LIVERWORTS (Hepaticae). Mainly land plants which have their sexual organs confined to definite parts of the plant. The liverwort plant has a flat leaf-like body which may be forked many times. It grows in close contact with the ground which is often very damp and may sometimes be under water (*e.g.*, aquatic forms). The lower surface of the body bears fine hairs (rhizoids) which attach the plant to the soil and also absorb food materials. Reproductive organs are borne on stalks.



The liverwort plant bears male and female organs. Male and female cells (gametes) fuse forming zygotes which grow into spore producing plants.

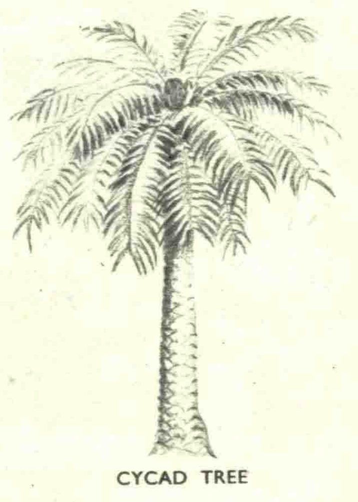
MOSSES (Musci) like liverworts have their sexual organs confined to definite parts of the plant. Their bodies contain some specialised tissue. Mosses mostly live on land, only a few being aquatic. Some live in very dry places such as stone walls. They have definite stems which bear rows of leaves. The bottom of the stem forms a rhizome.

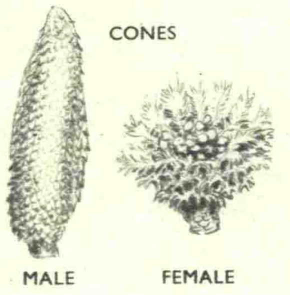


The moss life history is more or less identical to that of the liverwort. There are two generations, a spore producing sporophyte and a gamete producing gametophyte.

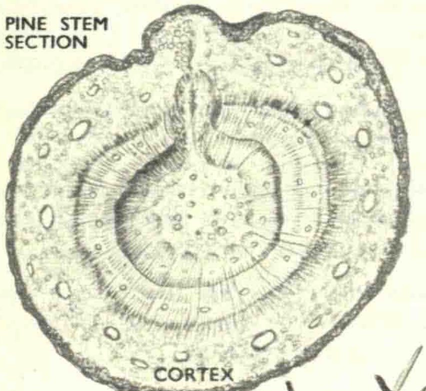
CYCADS. This plant group is widespread in some tropical regions of the world. It shows features associated with both ferns and flowering plants. They have a crown of fern-like leaves at the top of a stem which may be above or below ground. Male and female organs are on separate plants. Cycads produce naked seeds (not in an ovary).

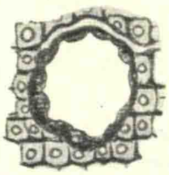
Many Cycads resemble palm trees. The large cones are borne inside the leaf crown. Pollen from a male cone is blown into a female cone. Sperms set free, fertilise the female cells.



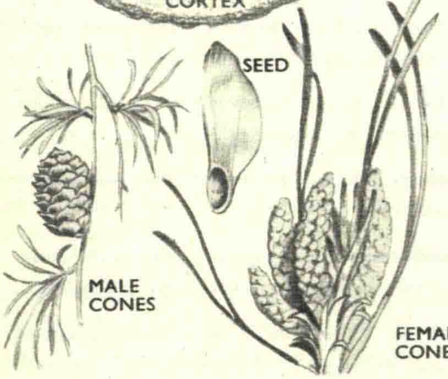


CONIFERS. With the Cycads and their relatives, the Conifers make up the Gymnosperm group of the Spermophyta (see page 49). Conifers are vascular plants with small needle-like leaves. Most are evergreen. Male and female cones usually occur on the same tree, and seeds are naked. The male sex cells have no cilia, unlike the Cycads. All Conifers are woody plants and in many areas of the world they form vast timber forests. The sequoia often grows to a height of nearly 300 feet and is the largest living thing.

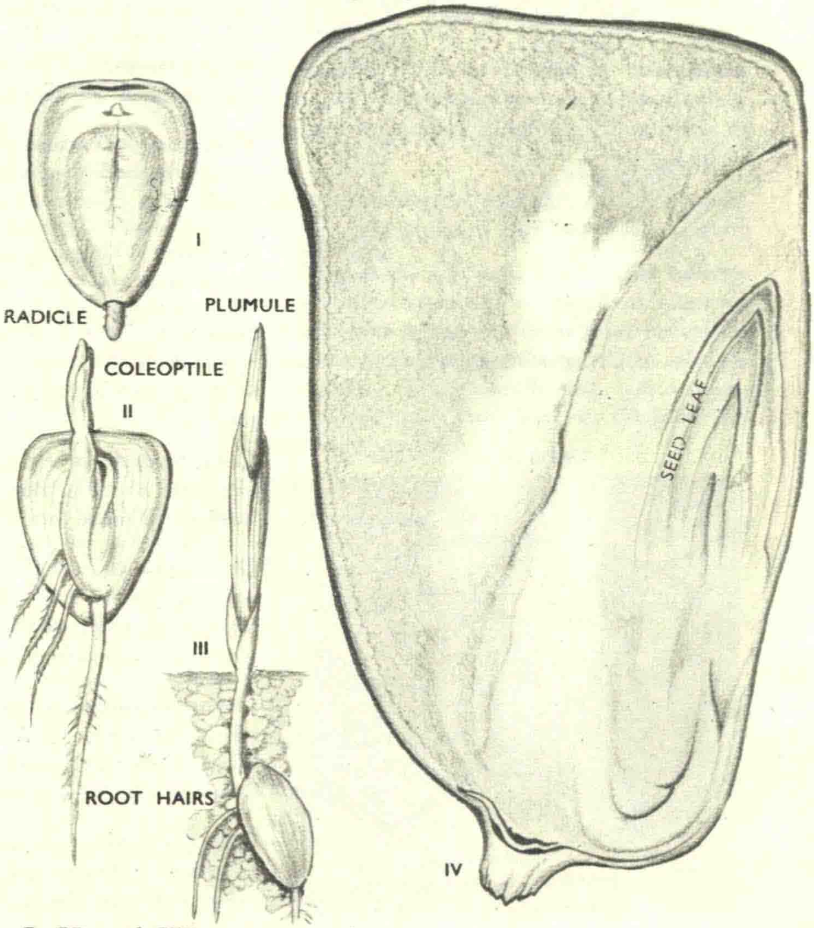




Pine stems have resin canals scattered through the cortex.

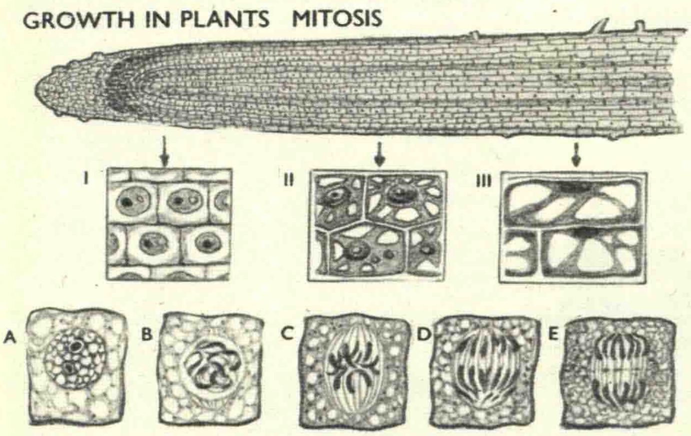


Female and male cones are usually borne on the same trees. Pollen from the male fertilises the female egg cells.

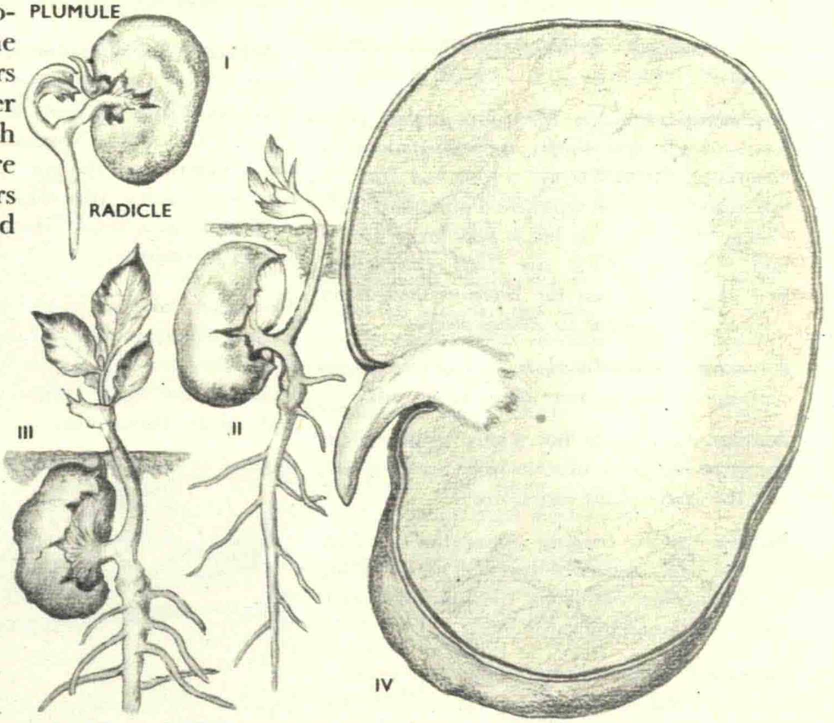


I, II and III are successive stages in the germination of the seed of a monocotyledon, maize (see Glossary). IV is a vertical section of a maize seed. The radicle pushes out first followed soon after by the plumule.

ANGIOSPERMS. This group with the Gymnosperms make up the Spermaphyta. It includes the most advanced plants. Like the Cycads and Conifers they produce seeds but they show real advances over other plants in possessing flowers and having a much more complicated vascular system. Also the seeds are enclosed in an ovary (not naked). In most flowers pollination is by insects and there are also complicated ways of dispersing seeds (see page 36).



The top diagram is a lengthwise section through a root tip. I-III are cells from three regions. As they age they contain more spaces (vacuoles). Behind the root cap is the growing region. Here cells divide (mitosis). A-E show successive stages in mitosis.



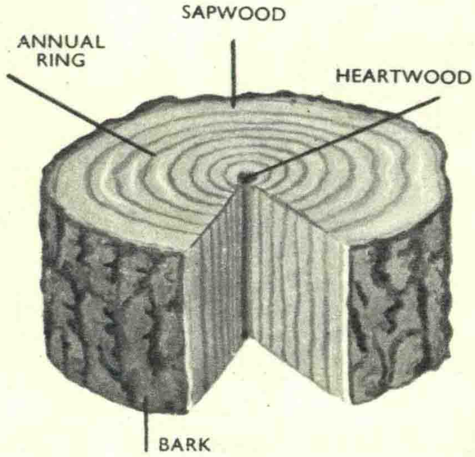
I, II and III are successive stages in the germination of the seed of a dicotyledon, the broad bean. IV is a vertical section through the bean seed. Note that the radicle grows into the main root, and the plumule is curved during its passage through the soil (cf. above).

Glossary

Abdomen In vertebrates this is the region of the body containing the digestive organs. In arthropods however, it is the hind region of the body.

Annual An annual is a plant which flowers, produces seeds and dies in one year.

Annual Ring The stem of a shrub or tree normally increases in thickness each year. The wood formed in one year is laid down as rings, each ring being known as an annual ring.



Antenna The jointed feeler of an arthropod.

Anther The swollen tip of a stamen (see page 36) which produces the pollen.

Anthropology is the study of man and his cultures.

Archaeopteryx is the name given to a fossil which was found in some rocks in Germany. It had teeth, a long tail and the forelimb had three separate digits, all reptile characters. But the brain was large and it had feathers which are bird characters. Scientists think that the Birds evolved from a form very similar to *Archaeopteryx*.

Asexual reproduction is reproduction without a male gamete being involved.

Auxins are plant hormones, produced in the growing points of roots and shoots, which control many plant functions.

Baleen is the feeding apparatus of many whales. It consists of rows of plates made of kerotin arranged in the mouth which strain off the plankton.

Biennial A plant which takes two years to produce food flowers and seeds.

Bilateral symmetry Animals which have parts of their body (*e.g.*, limbs) placed on either side in pairs are said to be bilaterally symmetrical, for example: insects, birds and mammals.

Brownian movement The continuous movement of minute particles in a suspension (*e.g.*, in a liquid). This movement is caused by the bombardment of the particles by the molecules of the surrounding fluid.

Carapace The hard protective shell which covers the bodies of many arthropods. It is made of a protein substance called chitin.

Cercaria The name given to one of the larval stages of some flukes.

Chaetae (**Setae**) are the small bristles found on many worms. The earthworm for example uses them to help it move. (See page 42).

Chlorophyll is the green pigment found in plants which is able to use the energy of sunlight to make food. (See page 34).

Chloroplasts are the small bodies, present normally in the leaf of a green plant, which contain the chlorophyll. Within the chloroplasts therefore, photosynthesis is carried on.

Chromosomes These are rods of material, in the nuclei of plant and animal cells, which carry the hereditary characters and divide during cell division. (See page 51).

Cilia are small hair-like growths from cells. In many protozoa they occur all over the body and beat rhythmically to enable the animal to move. They are also present in many other animals.

Cocoon The protective casing which surrounds the larval forms of many insects before they become pupae.

Coelom The scientific name for the true body cavity present in all animals with a body structure at least as complicated as that of Annelids. Normally it lies between the ectoderm and the gut. If you look at the section of the earthworm on page 42 you will see it as a black space surrounding the gut in the middle.

Commensalism is the association of two living things whereby one derives benefit from the other without harming it. For example the egret removes ticks from the hide of the rhinoceros.

Comparative Anatomy is the comparison of the structure of living things

Conjugation is the sexual fusion of male and female organisms. For example the joining together of two Spirogyra filaments. (See page 49).

Creodont An animal type which existed over 50 million years ago and which is the ancestor of many modern mammals.

Cuticle The hard protective covering found on arthropods. It is always non-cellular and may occur on other animals.

Cytoplasm is the contents of a cell other than the nucleus.

Dicotyledon is a plant which has two seed leaves in the seed. (See page 51). It also has leaves with parallel veins.

Dinosaurs or Terrible lizards were reptiles often of very great size which existed over 100 million years ago.

Dorsal is the term used when referring to the back of an animal.

Ecdysis is the process of shedding skin (moulting) in arthropods.

Ecology is the study of how and where animals live.

Ectoderm is the name given to the outer layer of an animal's body (*e.g.*, gut tube).

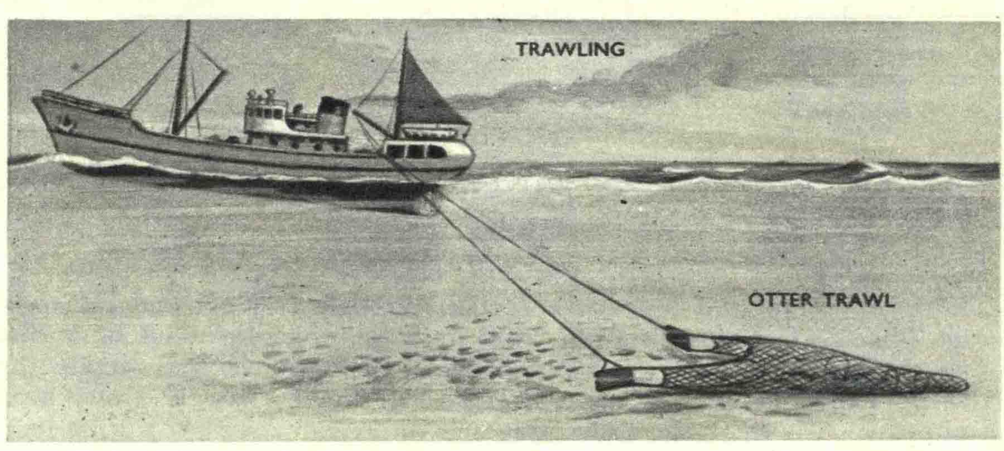
Embryo The name for a young plant or animal living on food provided by its female parent. It may refer to the developing plant within a seed or a chick within an egg for example.

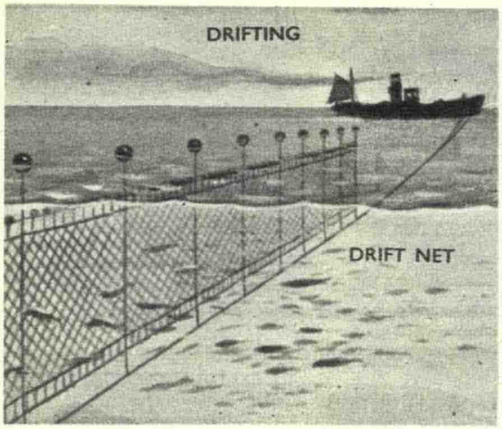
Embryology is the study of embryos and how they develop.

Endoderm is the name given to the inner layer of an animal's body.

Evolution is the theory that the higher forms of life have evolved from simpler forms by a process of slow, gradual change.

Fertilization is the process in which the male cell fuses with the female cell to reproduce.



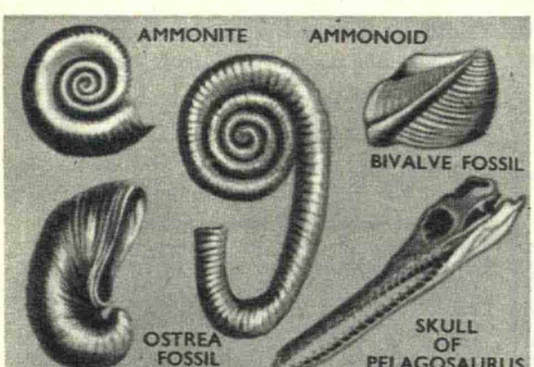


Fishing methods The methods of catching a fish will depend not only on its size but whether it lives near the surface or near the sea bed. A drift net is usually used for the former while various methods of trawling are employed for the latter. A method used inshore is called seining which involves surrounding the fish from the shore and pulling the nets into the shore.

Fission is the division of a cell into two or more parts, for example the reproduction of *Amoeba*.

Flagella are long whip-like " hairs " which grow out from a cell and by beating enable an animal or part of an animal to move or cause movement.

Food chain All animals depend on plants for their food whether they actually live on plants or other animals. For example the whale lives on tiny shrimps as its main form of food, but these live on smaller organisms which may be plants or animals, which in turn may live on yet smaller organisms.



Fossils are the preserved forms of animals and plants which have lived in the past. They are usually found in rock though some smaller animals have become trapped in amber (*e.g.*, insects, see Page 129).

Gamete is the name for the sex cell of an organism, *i.e.*, sperm or ovum.

Ganglion A collection of the cell bodies of nerve cells.

Gene A small part of a chromosome which controls one or more hereditary characters.

Genetics is the study of inheritance in both animals and plants.

Geotropism is the response of plants to gravity.

Germination is the first stage in the development of a plant spore or seed.

Gills are flap-like pieces of tissue used in respiration by animals that live in water.

Globigerina is an animal belonging to the Protozoa. It has a chalky skeleton and occurs in such large numbers in the sea that its empty shells form deposits (oozes) over vast areas of the sea floor.

Holophytic describes the type of nutrition which is typical of plants, *i.e.*, the manufacture of food by photosynthesis (see Page 34).

Holozoic describes the type of nutrition typical of animals.

Ichthyosaurs were reptiles which lived 150 million years ago, in the sea.

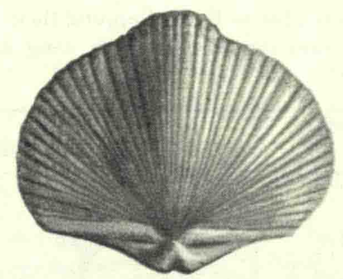
Inflorescence The cluster of flowers of a shoot (*e.g.*, lilac).

Larva is the name given to a stage in an animal's development.

Lichens are a group of non-flowering plants which are often seen growing on rocks and the bark of trees. They are in fact made up of fungal and algal cells which live together symbiotically (see symbiosis).

Megalopa is the name given to one of the larval stages of some crabs.

BRACHIOPOD FOSSIL

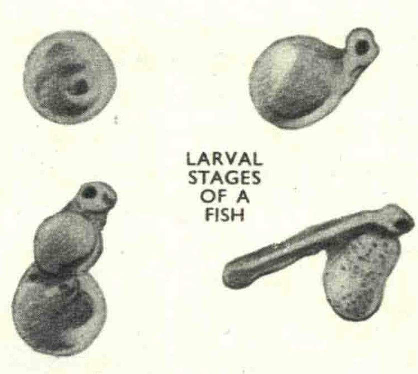


Meiosis The process of cell division by which the number of chromosomes in body cells is reduced to the number in the sex cells.

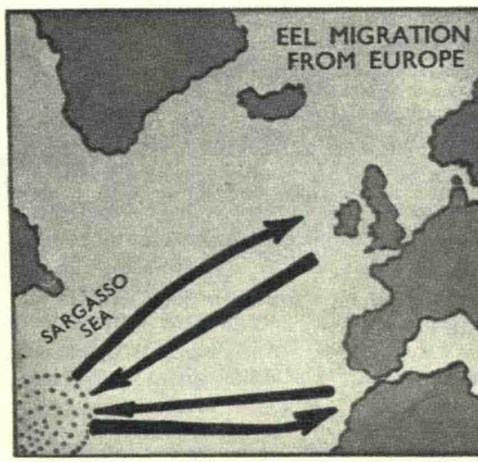
Mesogloea is the layer of jelly lying between the ectoderm and endoderm in coelenterate animals (*e.g.*, jellyfish).

Metamorphosis An animal which undergoes changes involving forms which are unlike the adult during its development is said to undergo metamorphosis (see Page 39).

Metazoa A group of the animal kingdom made up of animals with many celled bodies.



Migration is the regular movement of an animal from one place to another, usually annually. For example the starlings to Africa in winter and back to England the following summer.



Mitosis is the process of cell division where there is no reduction in the chromosome number (see Meiosis). This occurs in both plants and animals during growth (see Page 51).

Monocotyledon A plant which has one seed leaf in the seed (*e.g.*, wheat).

Muller's larva is the name given to the larval stage of some flatworms.

Mutation is a change in a gene during the production of new plants or animals which causes the new form to be unlike its parents. For example, scientists are able to breed strains of plants and animals which are hardier and better yielding than previous forms (see Page 12).

Mysis A larval form found in some Crustacea.

Nauplius The name given to the first larval stage of most Crustacea.

Nematocyst is a specialised type of cell found in many coelenterates (*e.g.*, *Hydra*) which is used both for catching food and self-protection.

Notochord The stiff but bendable rod which is found under the nerve chord in all chordates at some stage in their life.

Oozes are formed mainly from the shells of dead foraminiferans and radiolarians (*e.g.*, *Globigerina*) (see Page 8).

Osmosis is the movement of water perhaps with a few molecules of dissolved solid through a semi-permeable membrane (see Page 35).

Ostracoderms A group of primitive fishes which lived over 300 million years ago.

Parapodia The leaf-like limbs which many worms use for swimming, *e.g., Tomopteris* (see Page 42).

Parasite An animal or plant which lives on or in another organism causing the other harm (*e.g.*, tapeworm in dog).

Parthenogenesis The development of an egg without fertilization. Many greenfly develop in this way.

Penicillin is an anti-biotic extracted from the blue mould *Penicillium* (see Page 49).

Perennials are plants that continue to produce flowers and seeds year after year.

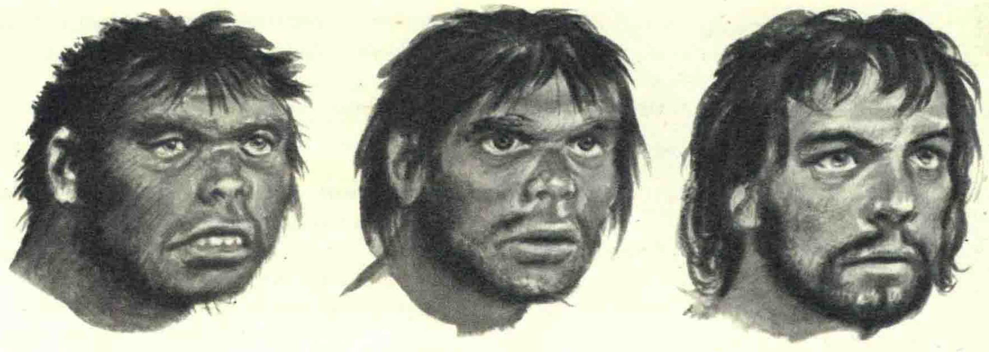
Phloem Large plant cells found in higher plants (all flowering plants) with sieve-like communicating walls which enable food materials to pass from one part of a plant to another.

Phyllosoma The name given to the late larval stages of some crustaceans (*e.g.*, lobster).

Placoderms A group of fossil fishes which were the first vertebrates to have jaws. These lived about 300 million years ago.

Plankton The animal and plant material which floats just below the surface in fresh and sea water. The largest animal group in the plankton is the Crustacea, and the largest plant group is the diatoms. Animal plankton is termed zooplankton and plant plankton is termed phytoplankton.

Plasmolysis The shrinkage of the cytoplasmin plant cells due to a loss of water.



PEKING MAN NEANDERTHAL MAN CRO-MAGNON MAN

Plumule The growing point of the young stem as it emerges from the seed.

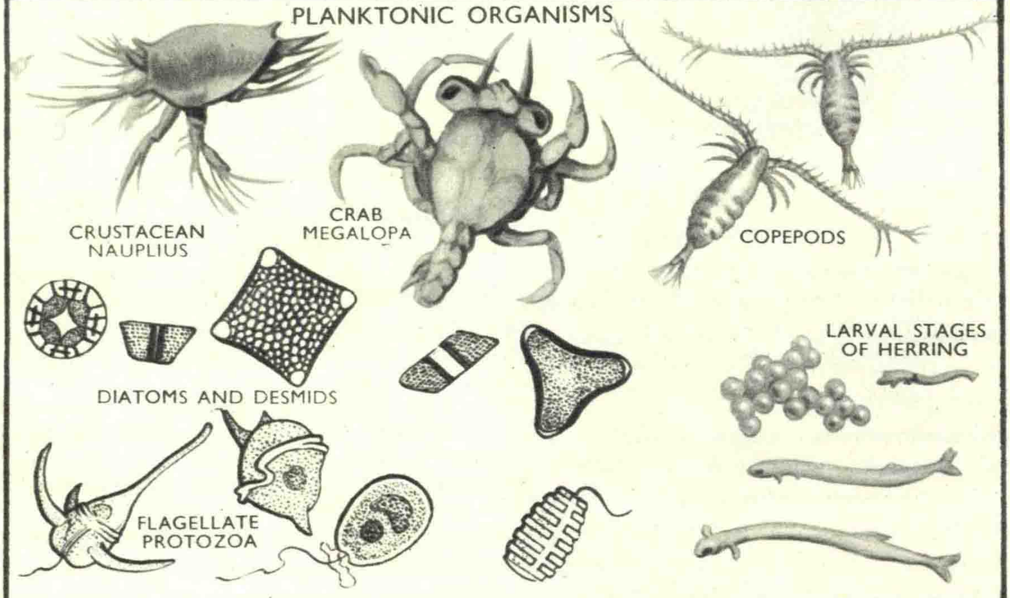
Pluteus The name given to several types of echinoderm larvae (see Page 45).

Prehistoric Man The earliest traces of man-like creatures seem to date from just over a million years ago. There is evidence that man-like apes, however, existed long before this. Peking Man walked nearly upright and had powers of communication. He is thought to have lived one million years ago. Neanderthal Man was much more like modern man, but he shuffled along with a slight stoop and did not have our intelligence. He lived fifty thousand years ago. Cro-Magnon Man was just about modern man. His origin is a mystery but he is thought to have come from North East Africa about thirty thousand years ago.

Protoplasm The substance within the cell membrane which is the living matter of the cell.

Pterodactyls were a group of flying reptiles with large wing membranes which they used for gliding over the sea using the air currents probably in much the same way as the albatross does today. It is unlikely that they were able to fly by flapping their wings. Pteranodon sometimes had a wing span of 25 feet.

PLANKTONIC ORGANISMS



Radial symmetry means the arrangement of limbs and other organs around a central point, *e.g.*, the starfish.

Saprophyte A plant which lives on dead organic material (remains of plants and animals). Saprophytes play a very important part in Nature by converting complex substances into simpler forms (*e.g.*, nitrates) so that they become available to green plants. Most fungi are saprophytes.

Saprozoic is used to describe animals which feed on dead organic material.

Sexual reproduction is reproduction involving the union of male and female gametes.

Spiracles are openings in the body walls of many arthropods (*e.g.*, insects) which lead to the tracheal (breathing) tubes, and admit air to the tissues. The name is also applied to a pore in front of the gill slits of some fishes.

Symbiosis is the term used to describe an association between two organisms for their mutual benefit (*e.g.*, hydra and the green alga which lives inside it).

Thallus is the name given to a plant body which is not divided into leaf stem or root (*e.g.*, liverwort).

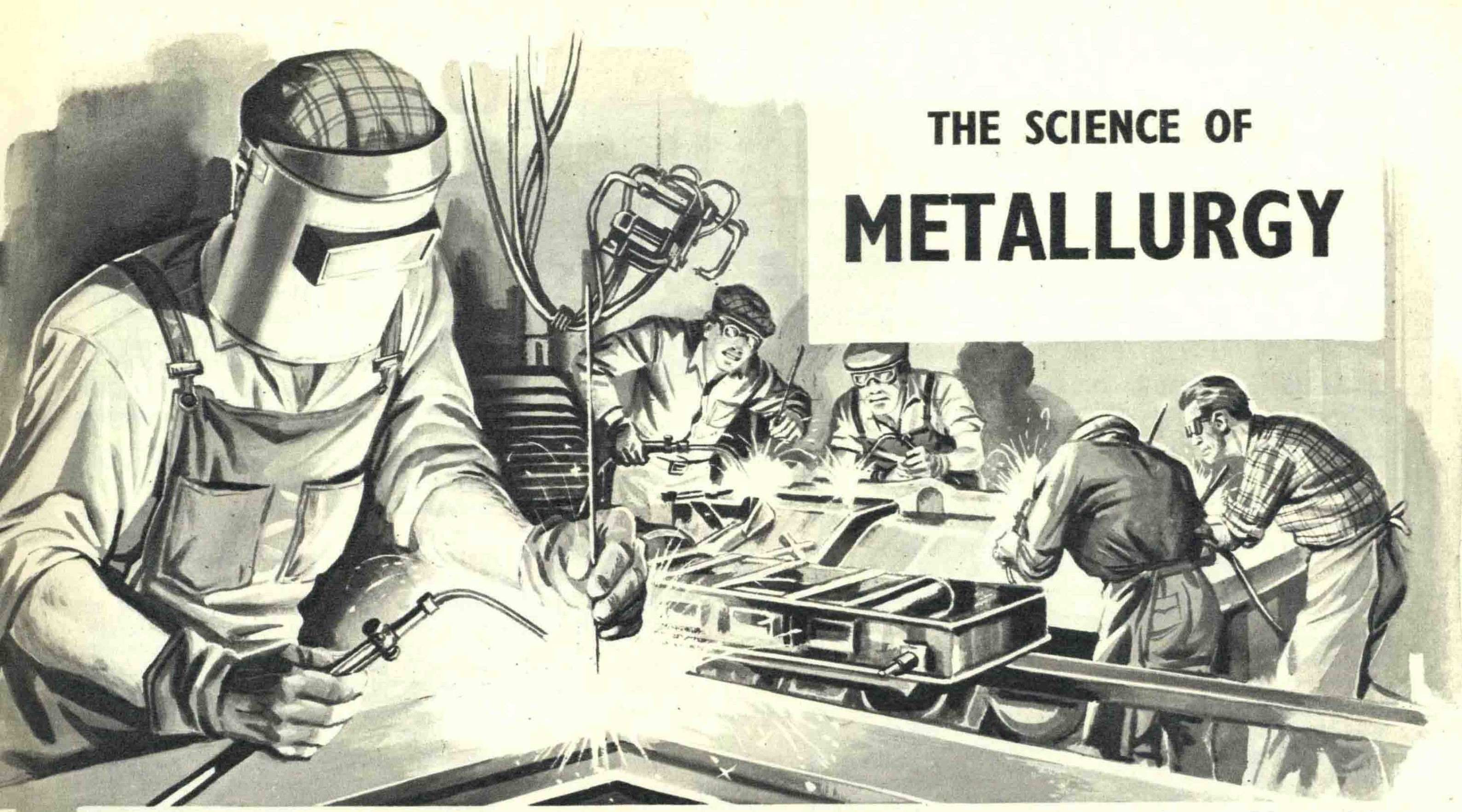
Thorax In animals with ribs, the region between the neck and the abdomen. In insects the region carrying legs and wings (between the head and abdomen).

Trachea The main air carrying tube in an animal's body. In insects, the tubes leading from the spiracles, and in vertebrates with lungs the tube which carries air from the mouth to the lungs.

Transpiration is the loss of water through the leaves of a plant as water vapour (see Page 35).

Vacuole A small space within the protoplasm of a cell. Plant cells have many vacuoles (see Page 51). Food vacuoles occur in Protozoa and are cavities in which the food is digested. Contractile vacuoles also occur in Protozoa and remove water from the animal.

Xylem The water conducting vessels of plants (see Page 34).



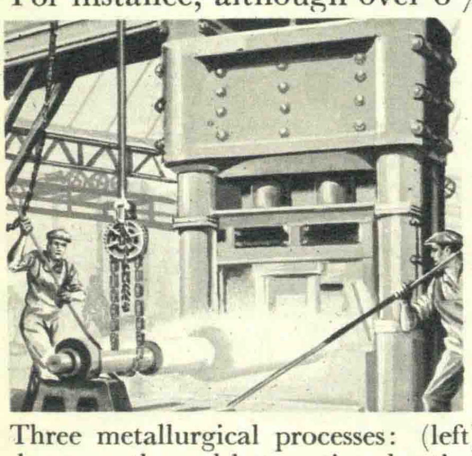
THE SCIENCE OF METALLURGY

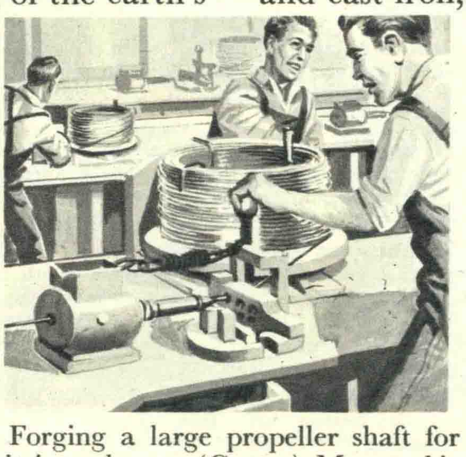
Gas welding. The workman looks through his protective mask as he uses an oxy-acetylene welder to join together two pieces of metal. As well as heating the two edges, he melts into the join metal from a rod in his left hand. The resulting weld will be as strong as if the metal had been all in one piece.

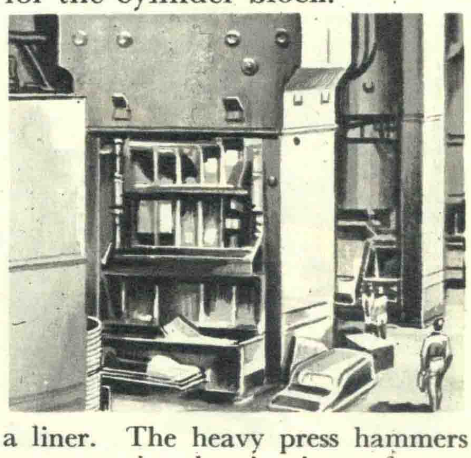
Metallurgy is the science of producing and working metals. Very few metals are found in their free state. They are usually firmly locked up with other elements in chemical compounds, from which they have to be released.

There are plentiful supplies of most metallic ores within the earth's crust, but the price of the metal does not only depend on the amount of ore available. The deposits may be difficult to mine, far removed from industry, and the extraction of the metal from the ore may be a complicated and expensive process. For instance, although over 8% of the earth's crust is aluminium, its method of extraction makes it more expensive than iron.

Pure metals lack strength, but if two or more metals are blended together we often find that the strength and other properties have been improved. These mixtures are called *alloys*. For example copper and aluminium are both fairly weak, but aluminium-bronze with 10% aluminium added to copper, is three times as strong as copper. Alloys are so widely used today that the only pure metals in a modern motor car will probably be copper, used mainly for wiring, and cast iron, for the cylinder block.







Three metallurgical processes: (left) Forging a large propeller shaft for a liner. The heavy press hammers down on the red-hot casting, beating it into shape. (Centre) Men making copper wire, drawing it out from a rod mechanically through a hole of the desired width. (Right) Making car bodies in a giant press. Flat sheets are forced slowly into shape by the press in a die or mould.

Glossary

Alloy is a blend of two or more elements, at least one of which is a metal, e.g.,

Brass = Copper + Zinc

"Duralumin" = Aluminium + Copper + Magnesium.

Steel = Iron + Carbon + Manganese

Aluminium is a light metal with a good conductivity of heat and electricity. It has an excellent resistance to corrosion. Pure aluminium is not very strong but many aluminium alloys have a useful combination of lightness and strength.

Annealing is a process of heating a metal or alloy to a temperature below its melting point, holding that temperature for a time, and then slowly cooling. Annealing usually confers softness.

Antimony is a hard brittle metal rarely used alone. It is alloyed with tin and lead in printers' type metal.

Beryllium is a metal which is stronger than steel but only one quarter of its weight. It does not corrode and maintains its strength at high temperatures. Beryllium is only now being commercially developed and it is finding important uses in the building of nuclear power stations.

A Carbide is a compound of an element with carbon. Metal carbides are usually extremely hard. Tungsten carbide is one of the most effective metallic cutting materials.

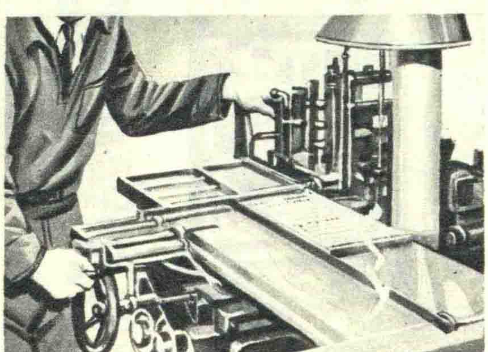
Chromium is a hard white lustrous metal. It is electro-plated on to nickel to give a durable surface. When alloyed with steel it gives a range of 'stainless steels'.

Cobalt is a greyish white metal which has important uses in alloys for magnets and cutting tools.

Copper is a reddish brown metal. It is ductile, malleable and an extremely good conductor of heat and electricity. Copper is used for electrical wiring, household goods and in a large number of alloys, including bronze, brass and copper coinage (see Ductility, Malleability).

Die Casting is a process in which molten metal is poured into a metallic mould or die, so that when the metal solidifies it takes up the shape of the mould.

Drawing is a process in which a cold rod of metal ($\frac{1}{4}$ in. diameter for steel) is pulled through a hole in a die so that its length is increased and diameter reduced. The process may be repeated eight or nine times using successively smaller holes until wire of the required diameter is obtained.



A type casting machine, in which printing type can be cast from lead, tin and antimony, at the rate of dozens of letters a minute.

Eros, the famous statue in Piccadilly Circus, London, is a fine example of the use of aluminium for artistic ends.

Ductility is the property which allows a metal to be deformed without cracking. e.g., drawn into wire.

Extrusion is the process in which a cylinder of metal is heated to a plastic state and forced through a die to make rods, tubes or strips.

Etching is the process of dissolving particular areas of a metal surface by chemical action, usually with acids.

Galvanising is the application of a coating of zinc on to iron or steel to improve corrosion resistances.

Gold is the most malleable and ductile of all metals. The pure metal is too soft to be used alone, so it is alloyed with other metals, usually copper and silver. The purity of the alloy is described by its 'carat' quality. The word 'carat' indicates a 24th part so that the 14 carat gold used for fountain pen nibs is 14 parts of gold to 10 parts of other metals.

Heat Treatments on metals can change their structure and physical properties. The metal, heated to some point below its melting point may be cooled slowly to confer softness (annealing) or it may be suddenly quenched, making it hard and brittle. Steel needles are hardened by this second method. They then need to be 'tempered' by reheating to remove the brittleness but retain the hardness.

Ingots are blocks of metal made by casting the molten contents of a furnace into open moulds.

Iron is the most important of all the metals since it is the main ingredient in all steels.

Lead is a soft metal, with a low melting point (327°C.), easily shaped and with excellent resistance to corrosion. It has important uses in plumbing, as electrical cable sheathing and in alloys for solder and type.

Magnesium is a silvery white metal with a specific gravity of 1.74. It burns with a brilliant flame provided there is a plentiful supply of air Its alloys combine lightness with strength and they are extensively used in the aircraft industry.

Malleability is the property of being able to be beaten into thin sheets without cracking.

Manganese is present in most steels (approximately $\frac{1}{2}$ per cent).

Mercury. See Chemistry Glossary.

Mild Steel is an alloy of iron containing very small amounts of carbon, silicon, manganese, sulphur and phosphorus.

Nickel is a hard white metal with outstanding resistance to corrosion used in electroplating and in alloys.

An Ore is a naturally occurring compound of a metal combined with another element or elements, e.g., Mercury ore, Cinnabar, Mercury sulphide HgS.

An Oxide is a compound of an element with oxygen (e.g., quicklime, calcium oxide).

Platinum is an attractive white metal which has a resistance to corrosion exceeding that of gold.

Plutonium is a radioactive metal which was used in the first atomic bomb.

Refractories are materials used for lining furnaces, which retain the heat without allowing the outer shell of the furnace to be damaged.

Rolling is the process in which ingots are converted into sheets by passing them between cylindrical rolls. The ingots are usually hot rolled first to 'break them down'. Cold rolling which allows greater control and accuracy may be used to complete the shaping.

Silver is an attractive white metal with good resistance to most types of corrosion.

Smelting is the process of converting an ore into its metal by heat and chemical action.

Soldering is the joining of metal parts with a metal or alloy having a lower melting point than any of the metal parts.

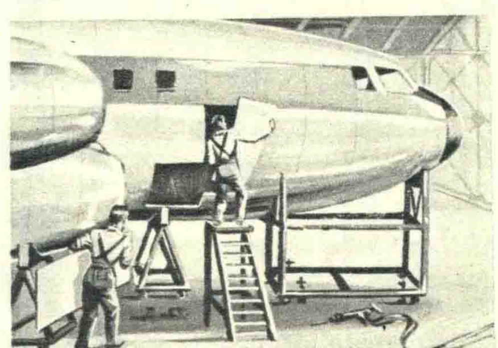
Tapping is the removal of slag or liquid metal from a furnace.

Tin is a white lustrous metal which is extremely ductile. Tin cans are made from mild steel sheets, coated in a bath of molten tin. Tin is a component of printing type alloys and solders.

Uranium is a radioactive metal used for the production of atomic energy for peaceful purposes.

Zinc is a moderately hard metal, without great strength, which tarnishes in air to form a film of oxide which then protects the metal from further attack. It is used for galvanising iron and in sheet form as a building material and in electrical dry cells and batteries. A modern car may contain over 200 parts which are zinc alloy die castings.

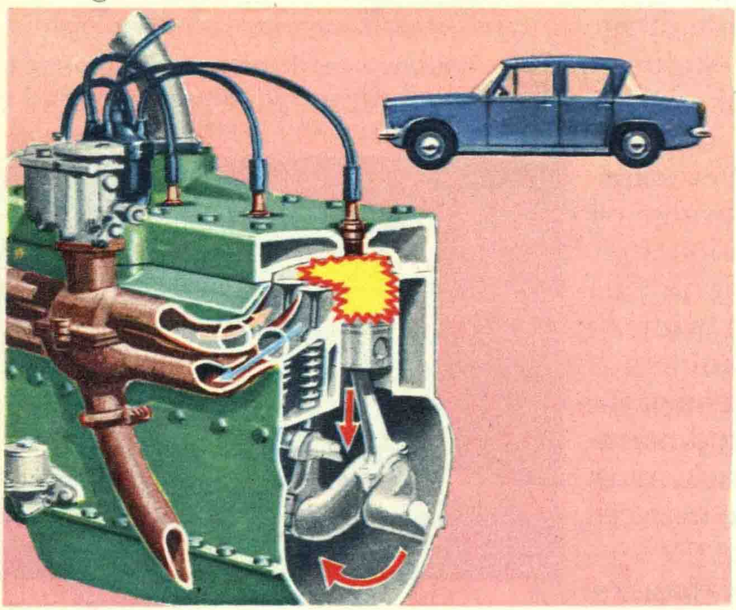
Welding is the process of joining two pieces of metal together by hammering or pressure, usually when they have been softened by heat.



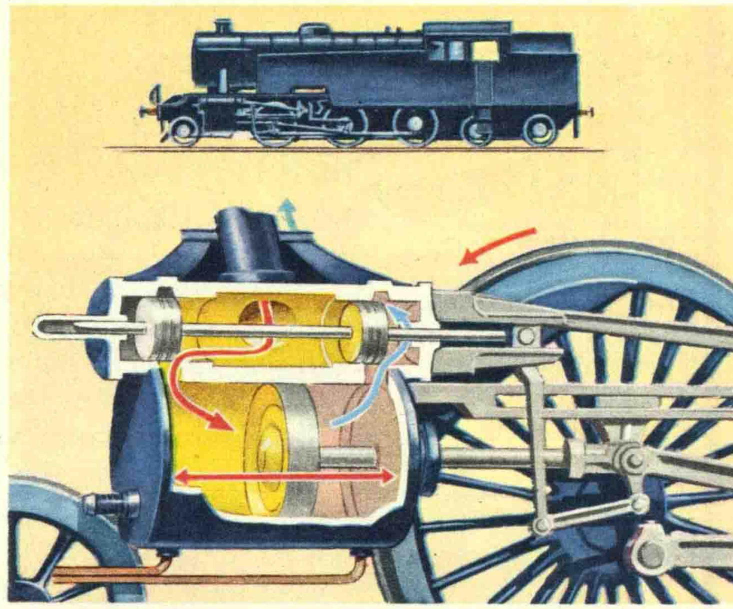
Many light, strong alloys, such as duralumin and magneson, have been developed for use in the aircraft industry.

THE SCIENCE OF HEAT

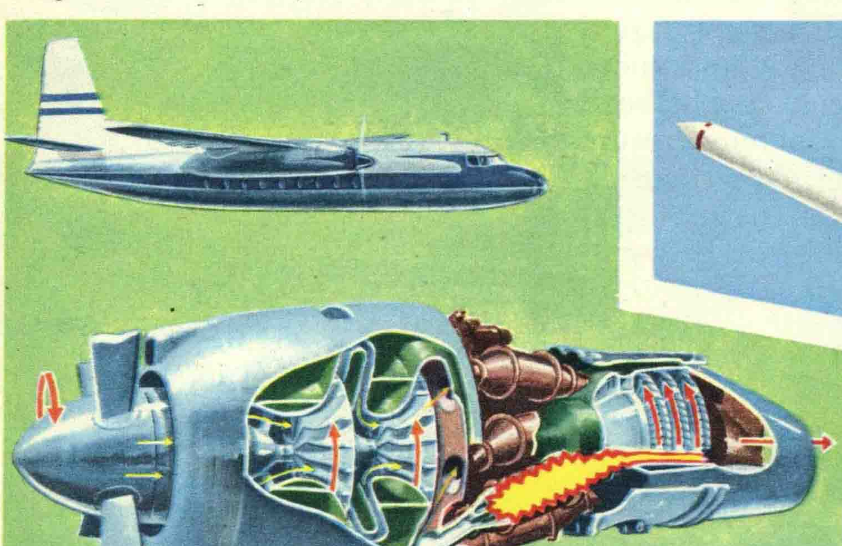
Heat is a form of energy. The molecules of a hot substance move about, and the higher the temperature the more rapid is the movement. At Absolute Zero (-273° Centigrade) molecules cease to move altogether. At 100° Centigrade the molecules of water are moving so fast that they break free of the surface to become vapour, and the water boils. Some of the ways in which heat energy is converted to mechanical energy are shown below. They all rely on the principle of expansion with heat (see page 58).

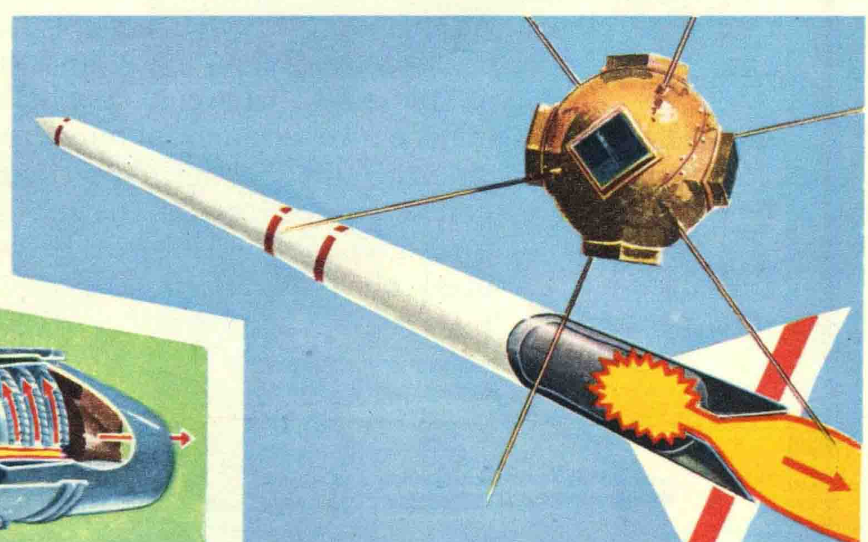


The internal combustion engine, used in the motor car, changes heat energy into mechanical energy. A sparking plug in the cylinder ignites a petrol and air mixture, causing an explosion. Rapid expansion of gases forces the piston down the cylinder.



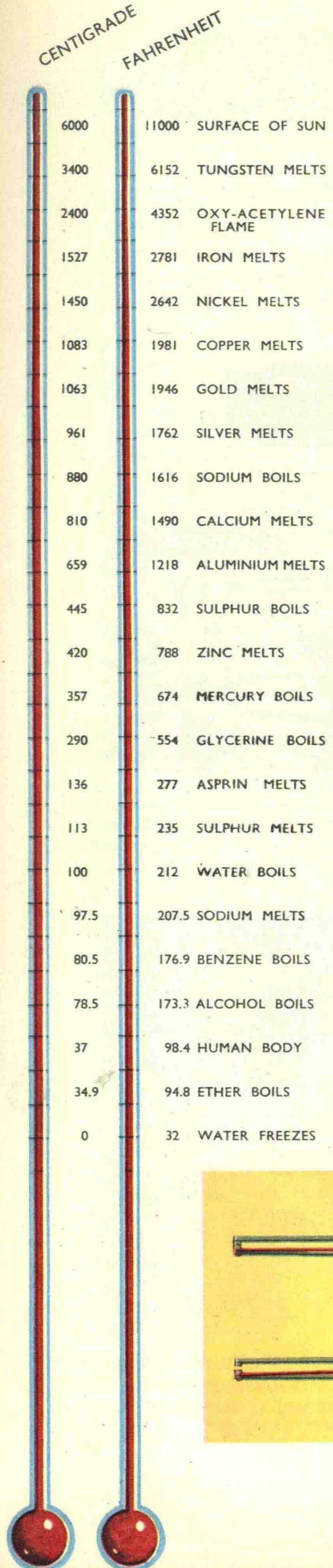
In the steam engine of a railway locomotive valves control the entry of steam into the cylinder. Such is the force of the steam, under great pressure, that it pushes back the piston, which in turn revolves the wheels by a system of levers.





(Left) The gas-turbine of an air-liner works by drawing in at the front air which is heated and expanded by hot gas. This mixture under pressure is passed through wheels which have vanes. As they revolve, the propellor is turned. (Right) A satellite-bearing space rocket, using a fuel to generate gas. The burnt gas expelled has the effect of urging it forward.

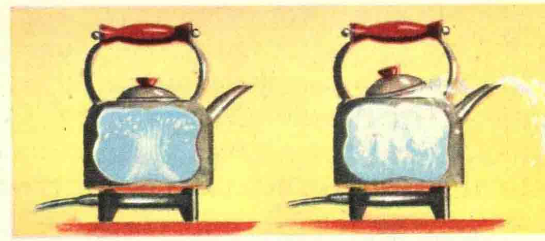
Expansion



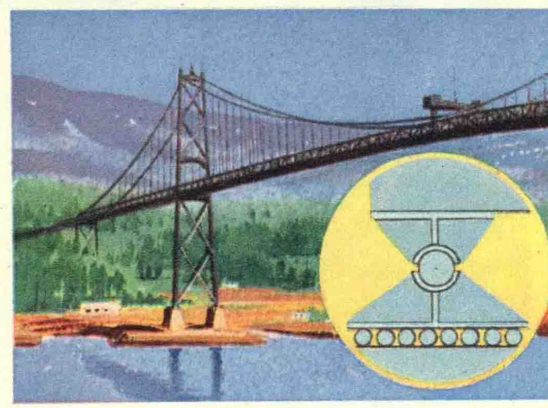
With very few exceptions all substances expand when they are heated. Gases expand most, solids least. All gases expand with rise of temperature at the same rate (at a given pressure), but different solids and liquids have considerably differing rates of expansion. In solids, for example, brass expands almost twice as much as steel for the same rise in temperature.

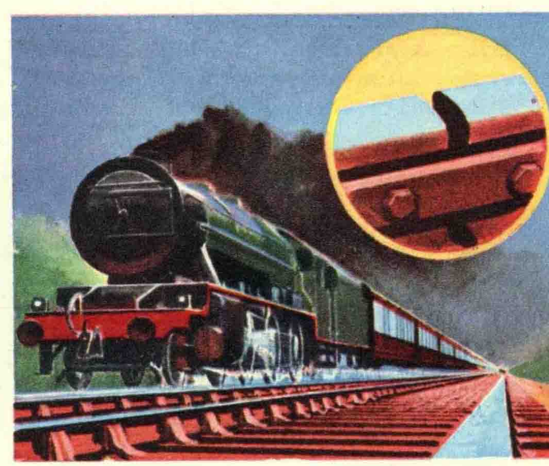
This expansion with rise in temperature can be both an advantage and a nuisance. Civil engineers building a bridge must make allowance for the expansion of the steel girders in hot weather. They sometimes build the ends of a bridge on rollers, so that the expansion may be taken up. A bridge is in fact longer in summer than in winter! A similar problem faces builders of railway tracks. The expansion of the rails in summer, which would normally tend to buckle the track, must be offset by leaving a space between each section of rail.

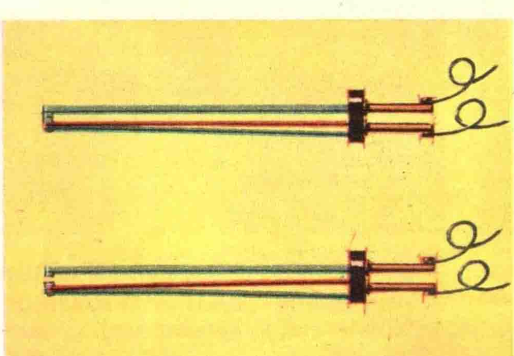
Advantage is taken of expansion with heat when it is used in instruments which measure or control temperature. The thermometers on these pages are fine tubes of glass, partly filled with mercury or alcohol. As the temperature rises the liquid expands and fills more and more of the tubes, where it can be read off as a measurement of temperature on either the Centigrade or Fahrenheit scales. Many of the temperatures given cannot in fact be measured on these particular thermometers (see page 65).

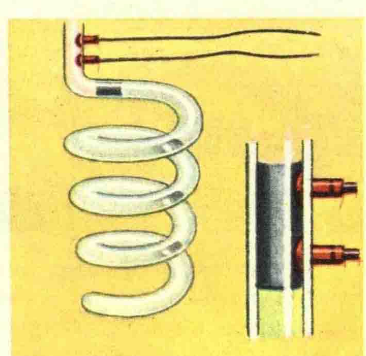


When boiling a kettle of water, we must not fill it too full when cold, for when heated the water will expand and overflow.





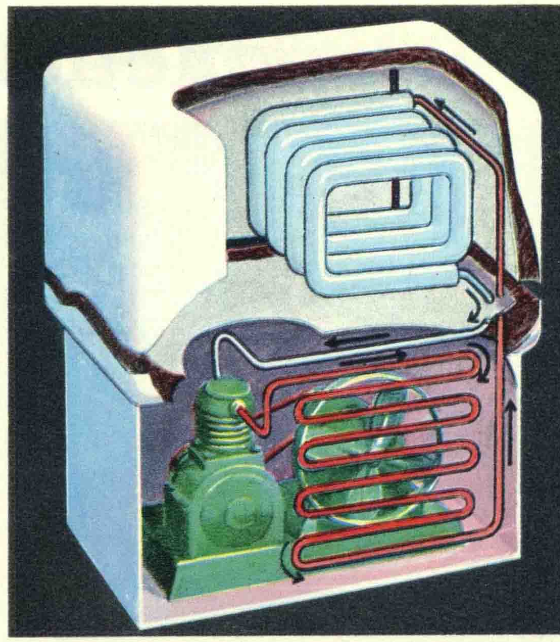




(Left) A fire alarm device, made of three rods. One is free, the others are joined together at the end. The lower one expands more on heating than the middle one. When fire breaks out, the lower expands, forcing the contacts at the end to meet. (Right) A thermostat, worked by expanding liquid in a sealed tube forcing a metal pellet up to connect two electrical contacts.

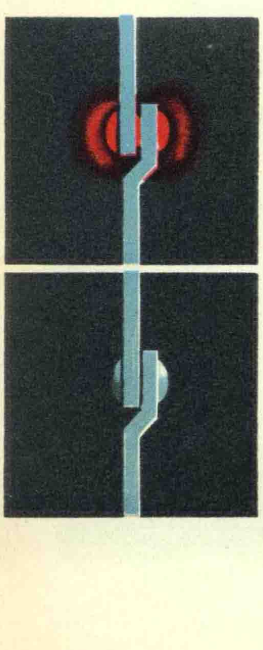
Latent Heat

Solids turn to liquids on heating, and liquids to gases. Heat is taken in while these changes of state take place. In the reverse process (gases to liquids, liquids to solids) heat is given out. This is known as latent (hidden) heat. This principle is used in the domestic refrigerator (*right*). Pressure is exerted on a gas, and it changes to the liquid state. Its latent heat is thus given out : this heat is taken from the liquid as it flows through cooling pipes. In another part of the apparatus, the pressure on the liquid is reduced, causing it to change again to gas. The heat needed for this change of state is taken from the refrigerator cabinet, thus reducing its temperature.



Contraction

Just as solids, liquids, and gases expand when heated, so they contract when they are cooled. The principles of contraction can be of great use to the engineer. Rivets hammered into metal plates to join them are applied red hot. Both ends of the rivets are flattened to hold the plates together as tightly as possible. When they contract, the plates are pulled flush against each other. The wheelwright makes a metal 'tyre' for a wooden wheel slightly smaller in circumference than the wheel, and heats it so that it will expand. While still hot he slips it over the wheel. As the 'tyre' cools, it contracts, making a tight fit. Motor engineers use liquid oxygen to cool new liners for the cylinders of car engines before fitting them. The contraction enables them to slip in easily, though at normal temperatures they fit tightly.



	CENTIGRADE	FAHRENHEIT
WATER FREEZES	0	32
MERCURY FREEZES	−38.8	−37.8
CARBON DIOXIDE FREEZES	−78	−108.4
ALCOHOL FREEZES	−117	−178.6
AIR LIQUIFIES	−192	−313.6
NITROGEN FREEZES	−209.8	−377.6
HELIUM FREEZES	−272.1	−458
ABSOLUTE ZERO	−273	−459.4

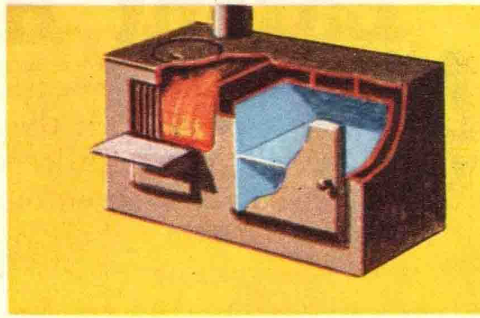
Conduction

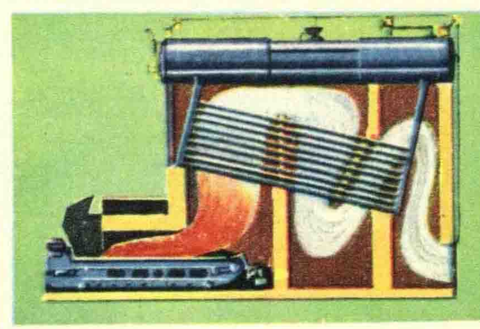
Heat is transferred from one place to another in any of three ways. Scientists call these three ways *Conduction*, *Convection*, and *Radiation*.

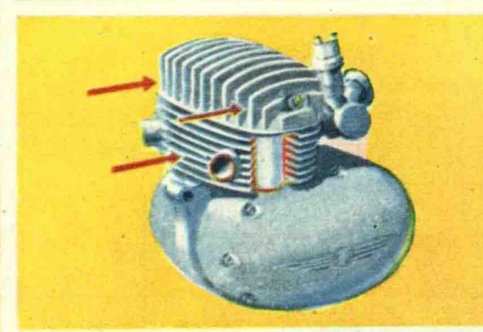
The diagrams on this page show examples of how heat travels by *conduction*. This means that it passes through a material from one molecule to the next, without the molecules moving substantially from their positions. The process may be compared to a chain of men passing buckets of water from a well to put out a fire. The men remain more or less stationary, and thus represent the molecules in matter. The buckets represent the heat moving along them.

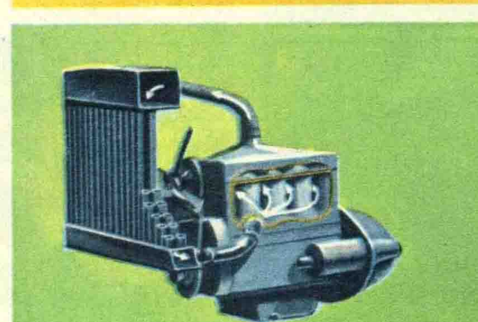
The heat from the kitchen fire passes to the oven wall by conduction. A kettle with a metal handle will pass heat along it unless the handle is insulated by some substance such as wood or plastic. Heat from a gas flame will travel along a metal tube by conduction. In a steam engine, conduction transfers the heat from the fire to the pipes in which the water is boiled.

Conduction may be used in cooling, too. The cold air blown across the cooling fins of a motor cycle engine " absorbs " by conduction the heat created by explosions in the cylinders. Similarly, in a water-cooled motor car engine, conduction works in passing the heat generated around the cylinders to the water which surrounds them. In both these last examples convection currents are also at work (see page 61).

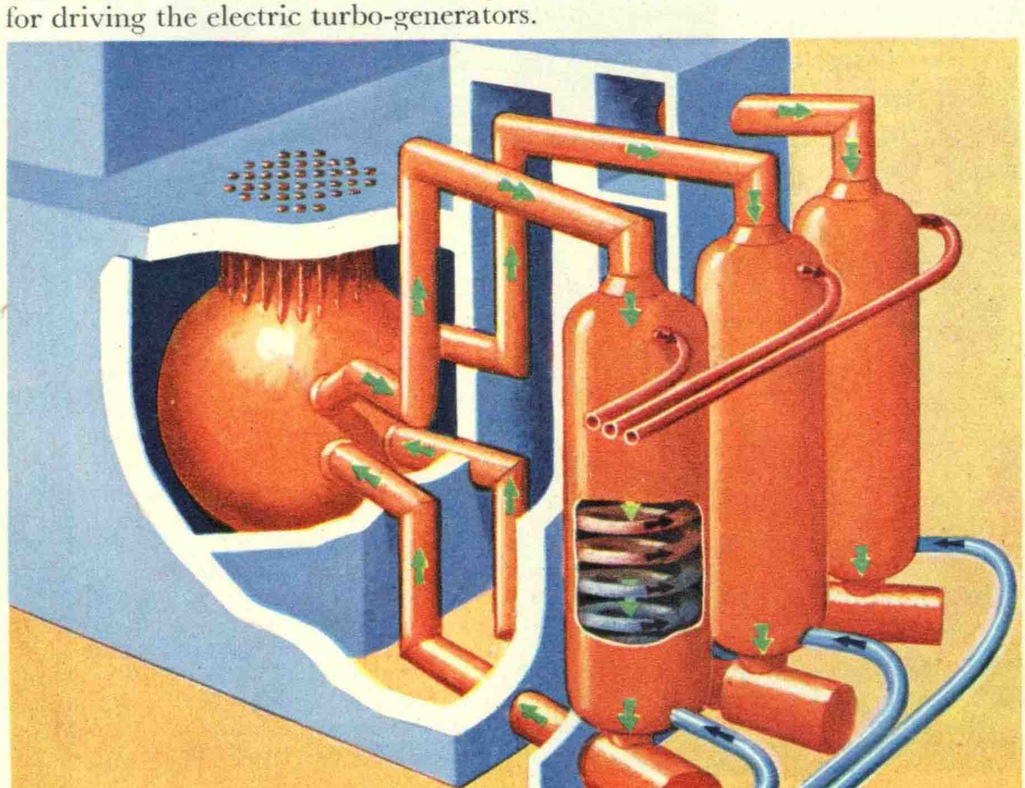




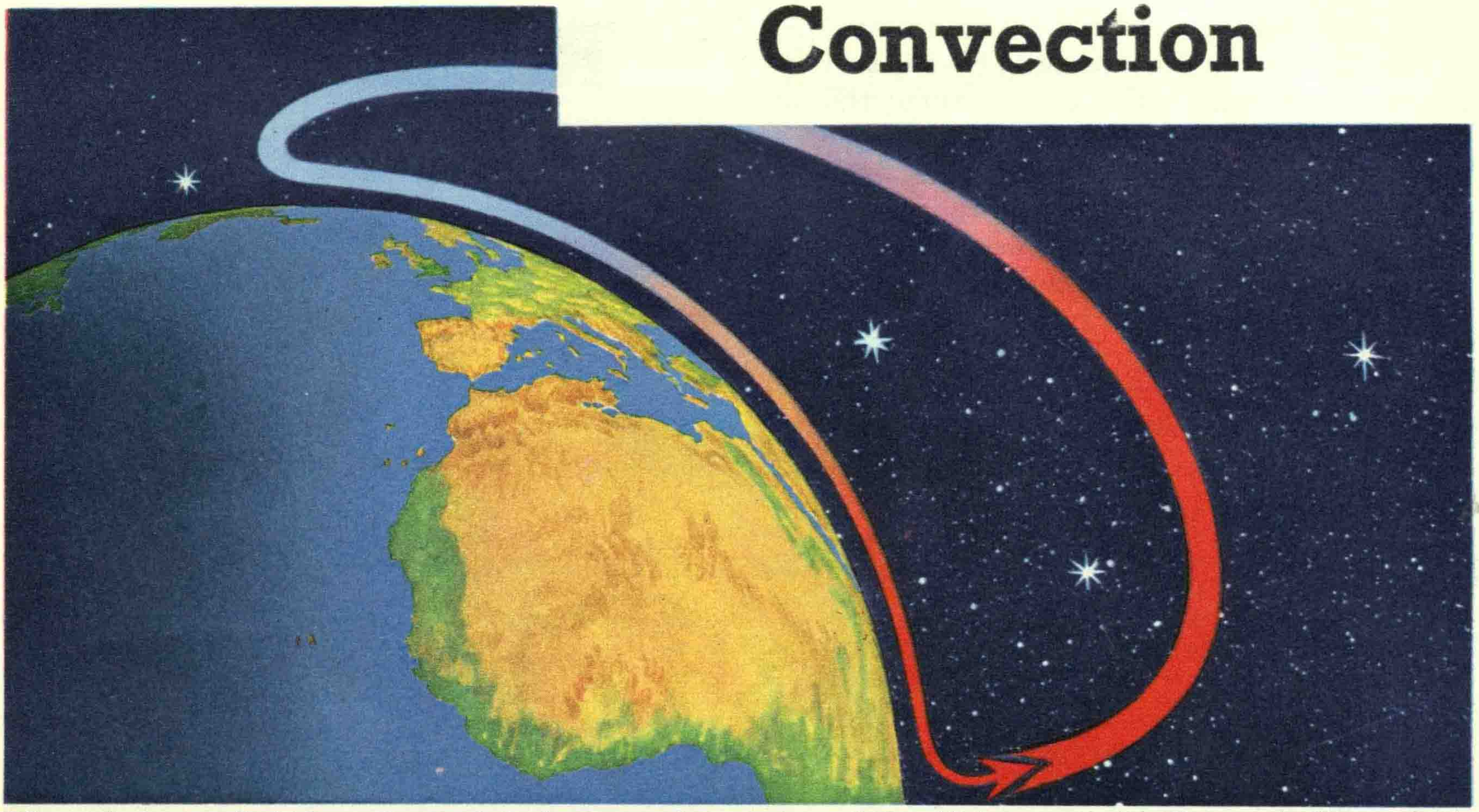




The heat exchanger of an atomic reactor can work both by conduction and convection. Heat generated in the reactor passes by conduction into the carbon dioxide which is circulated around the reactor. The hot gas then heats water in the heat exchangers, and this heat is used to raise steam for driving the electric turbo-generators.



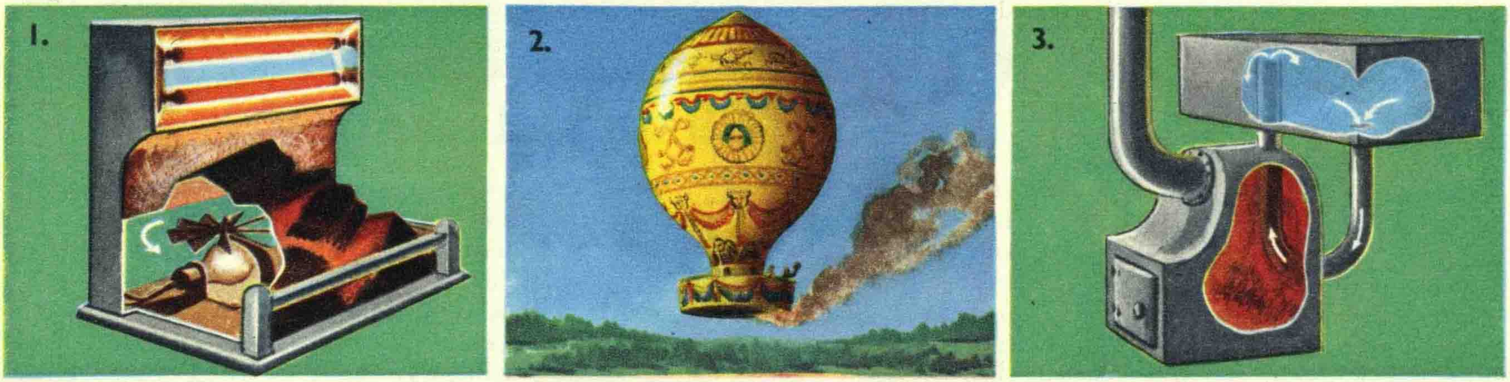
Convection



The main cause of winds on the earth is the convection currents of air which move as the diagram indicates. Air at the Equator is warmed and, becoming less dense, rises. Cold air from Polar regions moves in to take its place. The warm air flows to the Poles from the Equator, gradually cooling and descending as it goes.

The second method of heat transfer, *convection*, involves a movement of the matter conveying the heat, and is therefore applicable only to liquids and gases. When they are heated, they expand and become less dense (see page 97). Since the heated areas are less dense, they are lighter for their volume than the unheated areas of liquid or gas. What happens is that the heated areas tend to rise and so make room for the denser, heavier areas of unheated liquid or gas. As the colder unheated mass warms up, it in turn expands and becomes less dense.

A good example of convection in liquids is provided by the domestic hot water system. Cold water flows through the cistern to the boiler. There it is heated by conduction through the boiler walls. The warmed water is then less dense than the cold water around it and so is made to rise by convection. As it rises, it flows through a pipe leading to the hot water cistern. A regular current is set up in the hot water system, water rising as it is warmed, only to be displaced in its turn by even warmer water. The hottest water collects in the top of the tank.



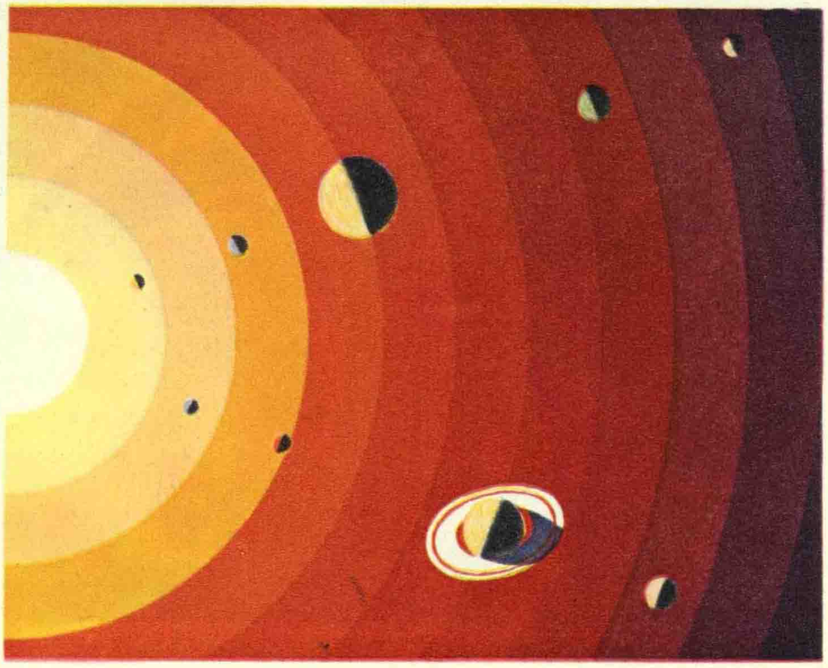
1. An electric ' mock coal ' fire has a spinning vane over a red lamp worked by warm air rising from the bulb, to simulate flickering. 2. The Montgolfiers' balloon ascending in 1783, was worked by a lighted fire, sending hot air by convection into the balloon. Being lighter than the air outside, the balloon rose. 3. Part of a domestic hot water system, explained above. The boiler heats cold water which travels by conduction into the upper part of the cistern.

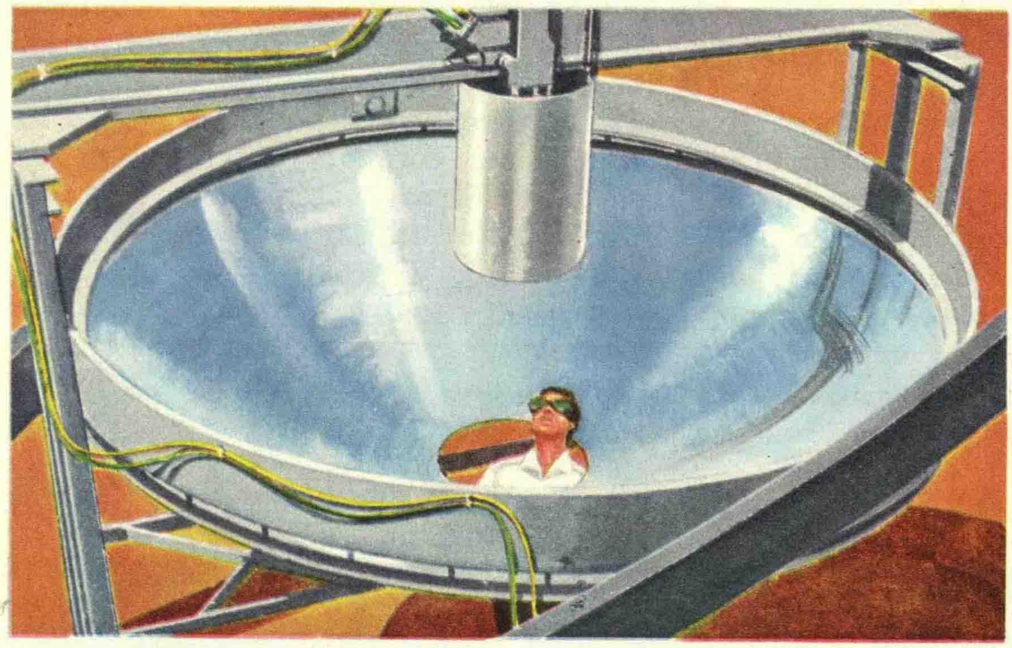
Radiation

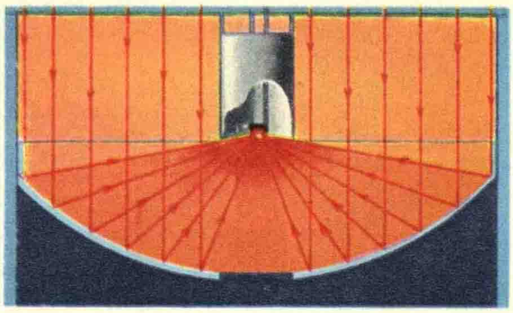
The third way in which heat can travel is by *radiation*. In fact the heat rays travel like those of light and scarcely warm the air. They can pass through the empty space of a vacuum. Yet they heat anything solid they meet. Radiated heat always travels in straight lines, just like rays of light. As with light rays, radiated heat rays can be reflected by highly polished surfaces and focused through lenses, directing it over a smaller area.

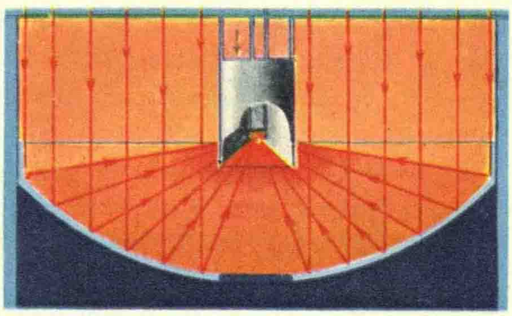
The diagram on the right shows how the sun's heat continually spreads itself over larger spheres as it travels outwards to the orbit of each planet. A square foot of the surface of Mercury gets more heat from the sun than a square foot of Pluto. Mercury, near the sun, receives heat rays when they are still highly concentrated. By the time they have reached Pluto they are shared out over the surface of a gigantic sphere corresponding to Pluto's huge orbit.

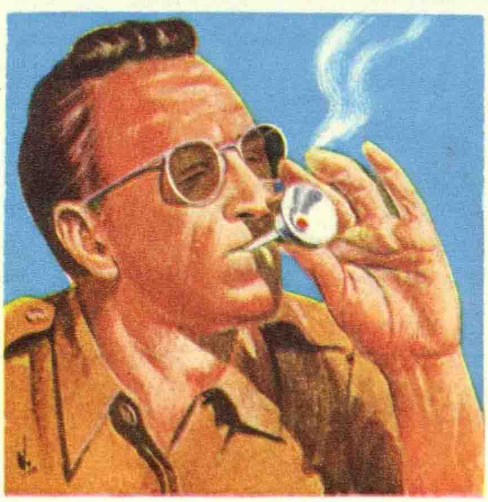
The planets in the solar system receive heat from the sun at its centre.









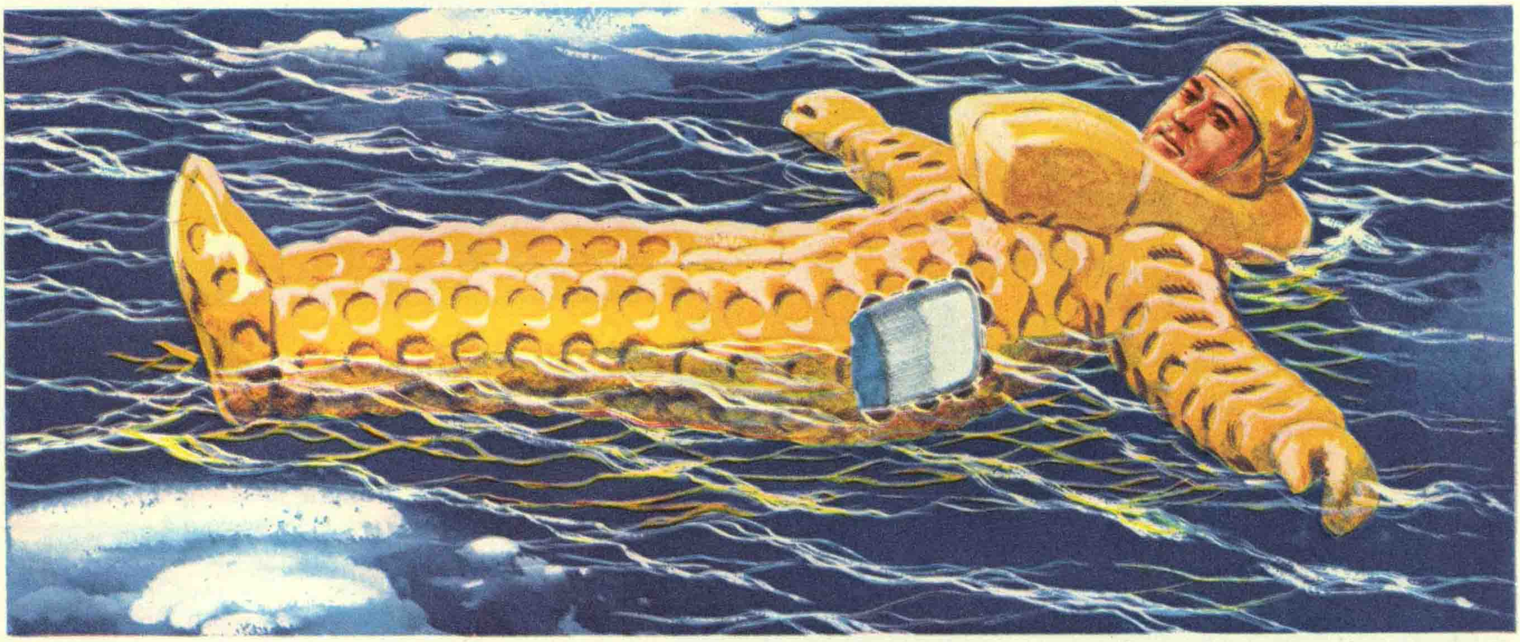


Using Radiation

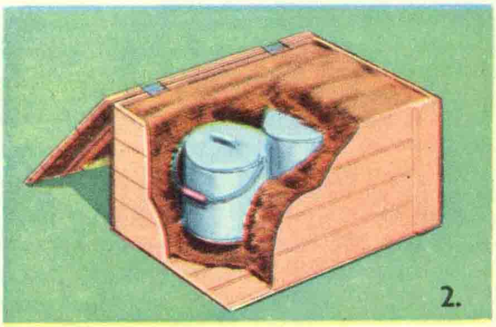
(Centre) Radiated heat travels in rays, and behaves in many ways like light It can be focused like light by the use of concave mirrors. The rays of the sun can be utilised in this way, and focused on to a unit which converts the heat energy into electrical energy. This piece of apparatus is called a solar furnace. The advantage of this method of obtaining electrical power is that it is very cheap, no expense being necessary on fuel. One disadvantage is that the solar furnace needs strong sunshine in order to be fully effective, a condition not always satisfied by the climate of Britain ! It seems unlikely therefore, that the furnace will ever become a major source of power in this country. (Bottom left) A man uses the same principle of using the heat rays from the sun to light his cigarette, using a concave mirror (rather like the reflector of a bicycle lamp) to concentrate the rays on to the end of it. The mirror is then removed. This can be done only in bright sunshine.

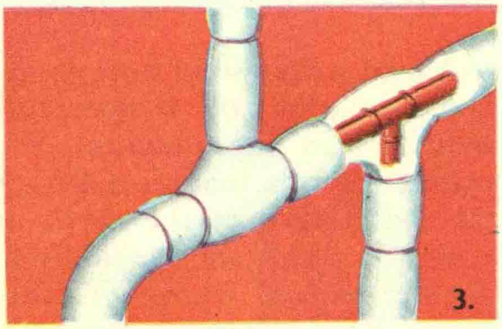
Insulation

The most important way in which the spread of heat may be checked or slowed down is by insulation. Briefly this means putting a barrier of some material which is a poor conductor of heat around it. Usually we want to conserve heat, to prevent it from escaping from ovens, pipes, houses, or even our bodies. The reverse process is sometimes needed, however, in such cases as the refrigerator, where the interior must be kept cool. On hot summer nights it is found that blankets on a bed actually help to keep the warmth *out*. Below are shown a few of the many practical applications of insulation in our everyday lives.

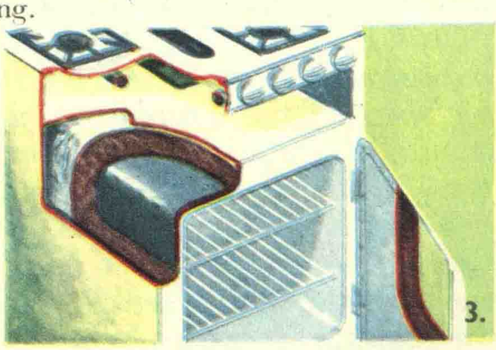


The Pilot who has had to abandon his plane in mid-ocean is by no means safe when he has landed on the sea. He must be protected against exposure, the chilling effect of cold and damp conditions, especially at night. The airman in the picture shows how some of the problems have been solved. He wears a survival suit of inflated rubber (air is a poor conductor of heat) which insulates him from the cold. It is brightly coloured so that it can easily be seen from the air. The air in the suit also helps to keep the airman afloat.

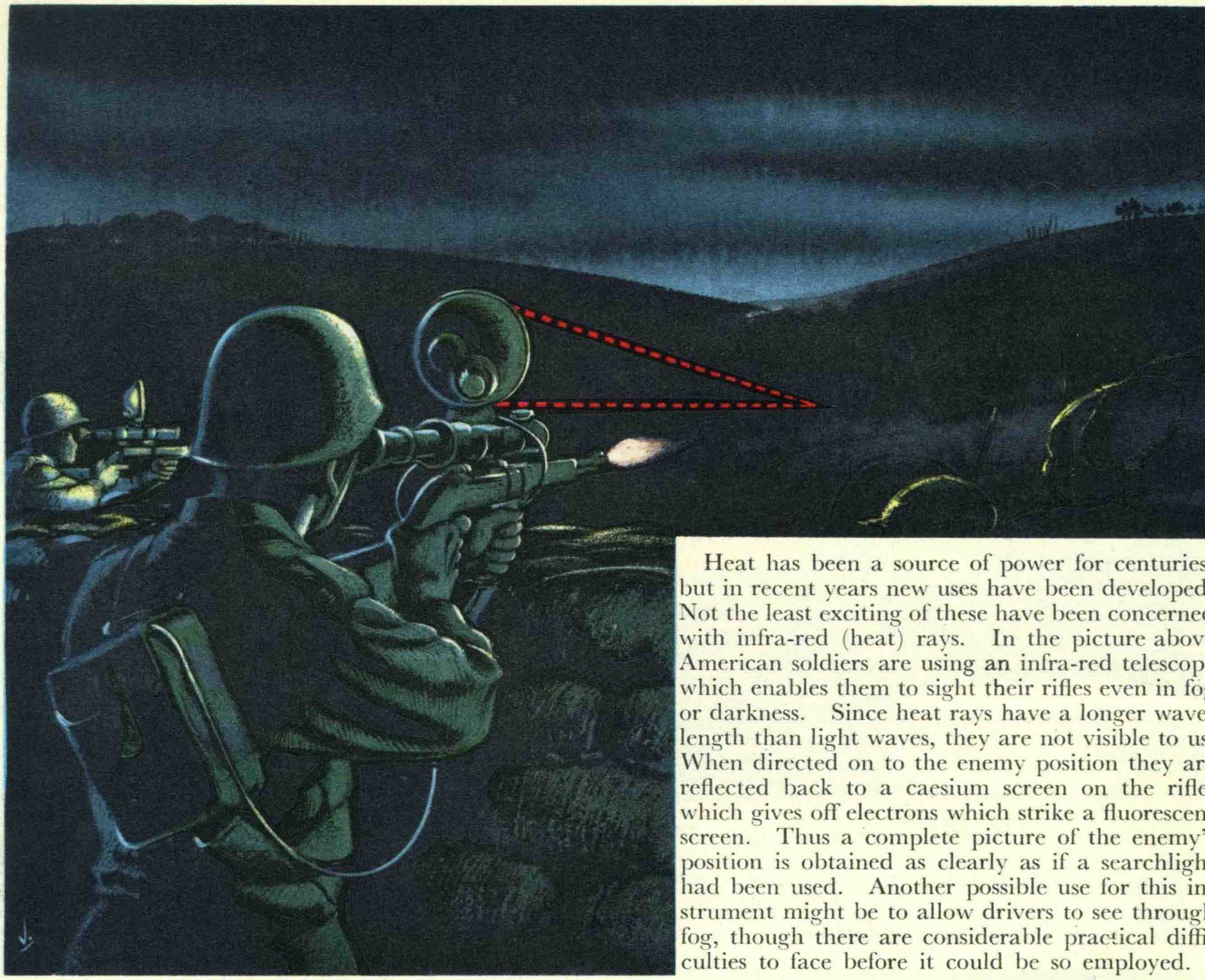




1. Insulating material (e.g. fibreglass) on the attic floor keeps in heat. 2. Heated food in an insulated haybox continues cooking. 3. Lagged pipes prevent the water in them from freezing.



1. Hot liquid in a thermos flask retains its heat because a vacuum surrounds it. 2. A Mongolian keeps warm in winter with heavy clothing. 3. A gas oven is insulated to keep in heat.

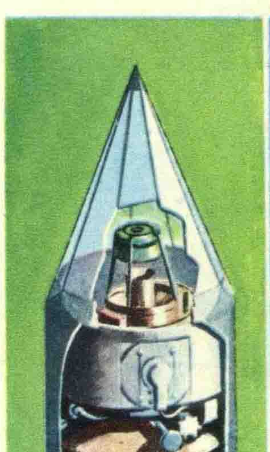


Heat has been a source of power for centuries, but in recent years new uses have been developed. Not the least exciting of these have been concerned with infra-red (heat) rays. In the picture above American soldiers are using an infra-red telescope which enables them to sight their rifles even in fog or darkness. Since heat rays have a longer wavelength than light waves, they are not visible to us. When directed on to the enemy position they are reflected back to a caesium screen on the rifle, which gives off electrons which strike a fluorescent screen. Thus a complete picture of the enemy's position is obtained as clearly as if a searchlight had been used. Another possible use for this instrument might be to allow drivers to see through fog, though there are considerable practical difficulties to face before it could be so employed.

Wonders of Heat

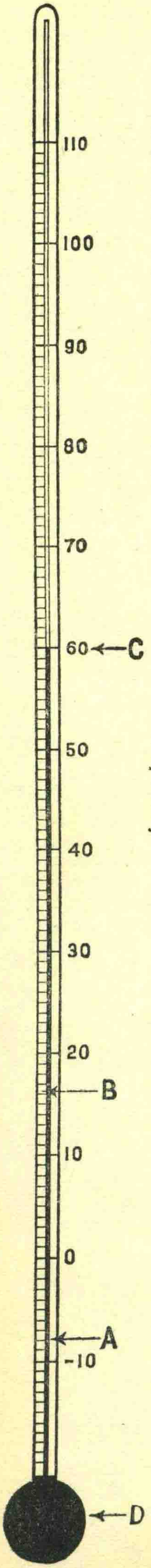
When we consider how great is the variation of temperatures achieved in the universe, it is something of a marvel that those on the surface of the earth are confined within such small limits. In the normal course of events men rarely experience temperatures of more than 150° F., or less than – 100° F. Indeed it is probable that we could not survive for long if these limits were substantially increased. Yet the sun's temperature at its centre has been estimated at 20,000,000° *Centigrade*. At the other end of the scale the surface temperature on Uranus is about – 200° C. (Absolute Zero is – 273° Centigrade).

The De Havilland Firestreak rocket uses an infra-red (heat) ray guidance system. In the head is a telescope which picks up the rays produced by the object (aircraft or rocket) which it is attacking. The homing system behind the telescope locks on to the source of the rays and guides the missile to it. It operates the rocket fins electrically.



Studying Heat

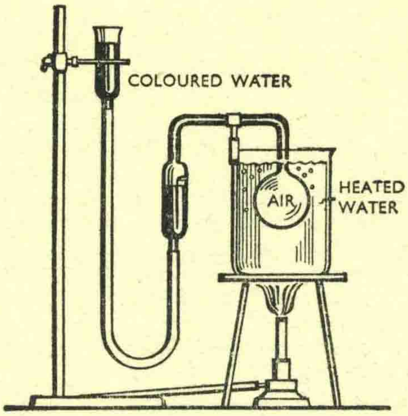
THERMOMETERS



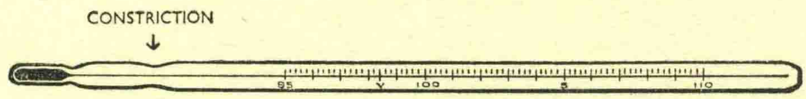
A thermometer is an instrument for measuring temperatures. Most thermometers work on the principle that solids, liquids, and gases expand on heating, and that in most cases a given amount of matter when heated to a given temperature expands the same amount. This is not always true of gases, however, and thermometers using gases must take other factors into account (see page 68).

The most common type of thermometer, that used to measure air temperatures both in and out of doors, consists of a thin glass (capillary) tube with a reservoir at the bottom. The reservoir is filled with mercury or alcohol. As the temperature of the air outside rises and heats the liquid, the latter expands and flows up the tube. The higher the temperature the greater the expansion and the higher the liquid rises. Since the amount of expansion is always the same with a given temperature, a scale is fitted to the tube so that the level of the liquid, and therefore the temperature, can be recorded.

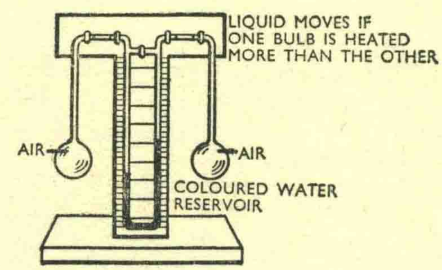
A very fine tube has to be used in the thermometer because the glass itself expands with the heat and the bore of the tube widens slightly. If the tube were wider this factor would tend to offset the expansion of the liquid to a considerable extent and it would not rise so far up the tube.



Air thermometer. The bulb in the beaker contains air, and is connected to a U-tube filled with coloured water. As the temperature of the air in the bulb rises (the water in the beaker being heated) it expands and pushes the coloured water along the tube.

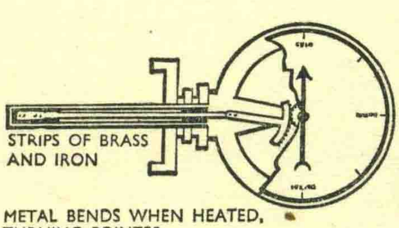


The clinical thermometer is a modified form of the instrument described above. Since the variation of body temperatures is so small, certainly no more than 10 *or* 15 *degrees from the average* (98·4°*F.*), *clinical thermometers are graduated only within these limits. There is a constriction or narrowing in the tube just above the reservoir so that the level of the mercury will not fall immediately the thermometer has been removed from the patient to be read.*



Differential thermometer. If the air in one of the bulbs is heated more than the other it will tend to expand more, pushing the coloured liquid in the middle off centre.

*Parts of a thermometer. (A) Capillary tube. (B) Graduations in temperature—usually either Fahrenheit or Centigrade (**see page 66**). (C) Mercury rising here to level showing* 60°*C. (D) Bulb or reservoir for mercury.*

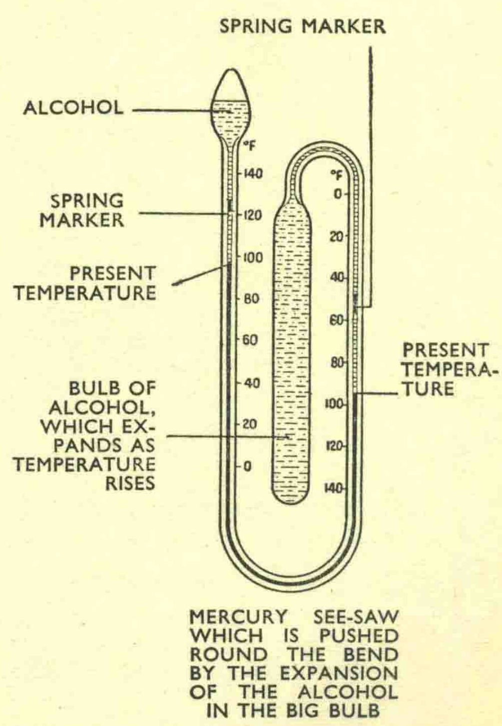


Calormeter. This is a thermometer using the unequal expansion rates of two metals. A rise in temperature causes the rod to bend, this being registered on a dial which records the temperature.

The maximum and minimum thermometer (right) is used to record the lowest and highest temperatures over a period of time. In the centre is a reservoir of alcohol, and between this and the alcohol at the other end is mercury, which "see-saws" as the alcohol expands and contracts with the changes in temperature. As the temperature rises, the alcohol in the central reservoir expands, pushing the mercury along the tube. This in turn pushes a spring marker up the tube on the left. As the temperature drops and the alcohol and mercury return towards the central reservoir, the spring marker remains in place, showing the maximum temperature against a scale. In returning to the reservoir the alcohol draws the mercury back with it, pushing up the spring on the right until the lowest temperature is reached. Thus both maximum and minimum temperatures are recorded over a specified period. The spring markers have to be reset with a magnet at the beginning of each period.

THE READINGS SHOWN ON THE MAXIMUM AND MINIMUM THERMOMETER ARE AS FOLLOWS:

MAX. TEMP.—120°F.
MIN. TEMP.—60°F.
PRESENT TEMP.—95°F.



TEMPERATURES

Temperature is the degree of hotness. The hotter a substance is, the higher its temperature. Temperature is measured on a scale, either as Fahrenheit or Centigrade, or one of the less common scales such as Réaumur. With the Fahrenheit scale the temperature at which water freezes is considered as + 32° and that at which water boils is 212°, both in standard conditions. In the Centigrade scale the freezing point is 0° and the boiling point 100°.

The rule to convert Fahrenheit readings into Centigrade is as follows:

$$C = \frac{5(F - 32)}{9}$$

where C is the Centigrade reading and F is the Fahrenheit reading.

Example: 68°F.

$$C = \frac{5(68 - 32)}{9}$$
$$= \frac{5(36)}{9} = \frac{5 \times 4}{1}$$
$$= 20$$

$\therefore$ 68°F = 20°C.

The rule to convert Centigrade readings into Fahrenheit is as follows:

$$F = \frac{9C}{5} + 32$$

Example: 65°C

$$F = \frac{9 \times 65}{5} + 32$$
$$= \frac{9 \times 13}{1} + 32$$
$$= 117 + 32 = 149$$

$\therefore$ 65°C = 149°F.

The reason why the above formulae are used is easily seen from the following information:

THERMOMETER SCALES

Scale	*Freezing point of water*	*Boiling point of water*	*No. of degrees between F. pt. & B. pt.*
FAHRENHEIT	32	212	180
CENTIGRADE	0	100	100

Note: the ratio of the difference between freezing points and boiling points of Fahrenheit and Centigrade is 180:100 =9:5.

ABSOLUTE TEMPERATURE

It is believed that the lowest temperature that can be attained is approximately 273° Centigrade below the freezing point of water, i.e. −273°C. This is called Absolute Zero. If we start counting from this point in degrees Centigrade, counting Absolute Zero as 0°, we call it the Absolute scale, and the degrees as degrees Absolute. Thus water

SOME IMPORTANT TEMPERATURES

Absolute zero	−273°C.	
Air liquefies	−190°C.	
Freezing water	0°C.	32°F.
Average body temperature of human in good health		98.4°F.
Boiling water	100°C.	212°F.
Dull red heat approx.	600°C.	
White heat	1,200°C. approx.	
Surface of sun	6,000°C. approx.	
Interior of sun up to	40,000,000°C.	

freezes at 273° Absolute and boils at 373°A. The rule for converting degrees Centigrade into degrees Absolute is:

$$A = C + 273$$

Example: 120°C

$$A = 120 + 273$$
$$= 393$$

$\therefore$ 120°C = 393°A.

Combining this formula with that used to convert Fahrenheit to Centigrade we can produce a formula to convert degrees Fahrenheit into degrees Absolute. It is as follows:

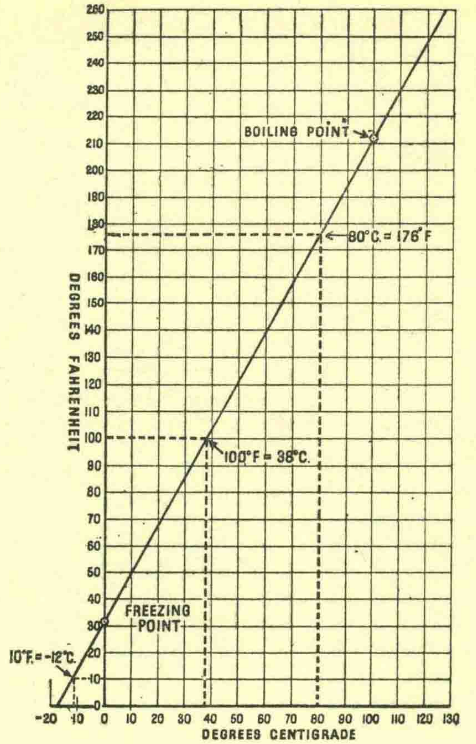
$$A = \frac{5(F - 32)}{9} + 273$$

Example: 131°F

$$A = \frac{5(131 - 32)}{9} + 273$$
$$= \frac{5(99)}{9} + 273$$
$$= \frac{5(11)}{1} + 273$$
$$= 55 + 273$$
$$= 328$$

$\therefore$ 131°F = 328°A.

Note: degrees Absolute are also called degrees Kelvin. Thus 328°A. = 328°K.

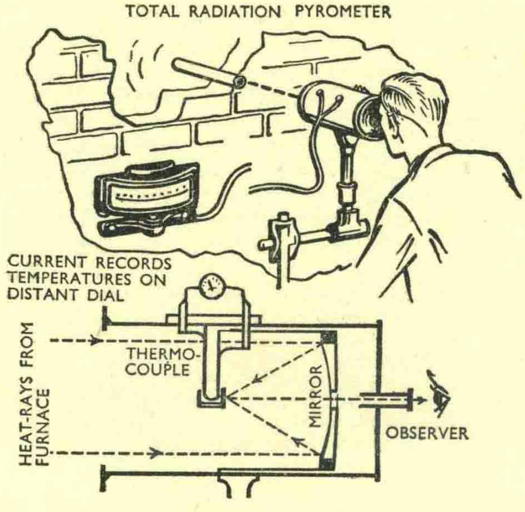


A graph which can be used to convert temperatures from Fahrenheit to Centigrade and vice versa.

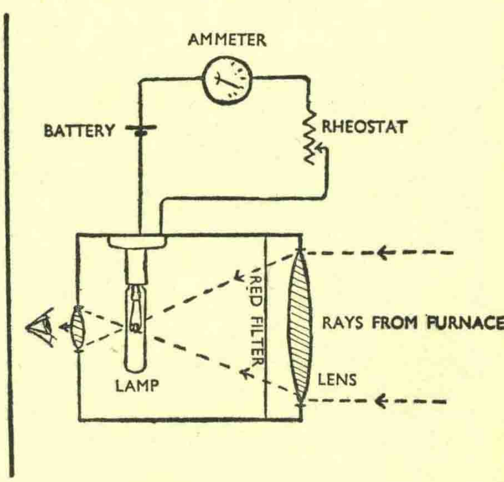
PYROMETER

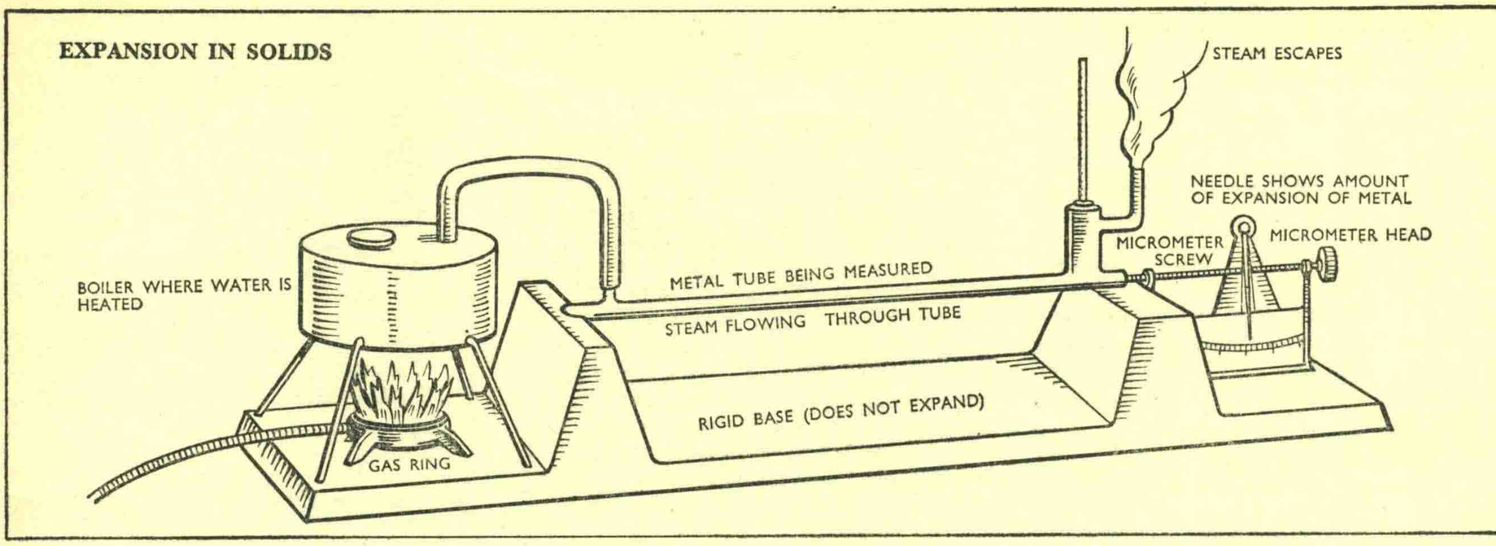
Special methods are required for reading the temperatures of furnaces, which are too high for mercury thermometers to be used. With the optical pyrometer (right) the operator looks at the open furnace through the instrument which contains a special electric lamp and battery. Adjustments are made until the white-hot filament of the lamp is invisible against the background of the furnace, and the temperature is read off on a scale. With the thermo-couple pyrometer (left) two different metal strips are joined together at one end. This end is exposed to the furnace. The other end, which stays cool, is connected to an electric meter which measures the tiny electric current set up by the action of heat on the junction. The dial is marked off to show the temperature of the furnace. (See below.)

TOTAL RADIATION PYROMETER



OPTICAL PYROMETER





A laboratory experiment to measure the linear expansion of a hollow metal rod. The apparatus is set up as shown. The micrometer screw (right) is turned to leave a tiny gap. As the steam flowing through the tube makes it hotter, the metal expands and closes the gap. The temperature is read off the thermometer, while the amount of expansion is recorded on the calibrated scale. Since the length of the rod is known, the coefficient of linear expansion can be roughly worked out.

LINEAR EXPANSION

The coefficient of linear expansion is the increase in length of unit length for a rise in temperature of one degree.

COEFFICIENTS OF LINEAR EXPANSION, FOR 1°C.

Note: the coefficient for 1°F. is $\frac{5}{9}$ as great in every case.

Aluminium	·000026
Brass	·000019
Copper	·000017
Steel	·000011
Concrete	·000012
Platinum	·000009
Glass	·0000085
Pyrex	·000003
Fused silica apparatus	·0000005
Invar (steel with 36% Nickel)	·0000009

These very small figures are difficult to visualise. Here they are again in another form, the increase in length of a rod 1 mile long for every 1°C. rise in temperature.

Aluminium	$1\frac{1}{2}$ inches
Brass	$1\frac{1}{8}$ inches
Copper	1 inch
Steel	$\frac{3}{4}$ inch
Concrete	$\frac{3}{4}$ inch
Platinum	$\frac{1}{2}$ inch
Glass	$\frac{1}{2}$ inch
Pyrex	$\frac{3}{16}$ inch
Fused silica apparatus	$\frac{1}{30}$ inch
Invar (steel with 36% nickel)	$\frac{1}{20}$ inch

Formula: where l = original length, t = rise in temperature, α = coefficient of linear expansion

Expansion = $l \times \alpha \times t$

Example 1: A bridge, made of steel and 1,000 yards long, has a minimum winter temperature of −10°C. and a maximum summer temperature of 40°C. What allowance must be made for expansion?

Expansion = $l \times \alpha \times t$ = 1,000 × ·000011 × 50
= 1 × ·011 × 50
= 0·55 yds.

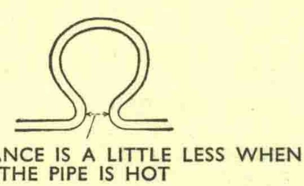
This is 1 ft. 8 in. approx.

Example 2: It is intended to provide a steel tyre for an aluminium wheel (which is 100 in. across at 22°C.) so that the tyre will just fit the wheel when the latter is immersed in solid carbon dioxide at −78°C. The tyre will, of course, not be cooled down before fitting. What should be the diameter of the tyre?

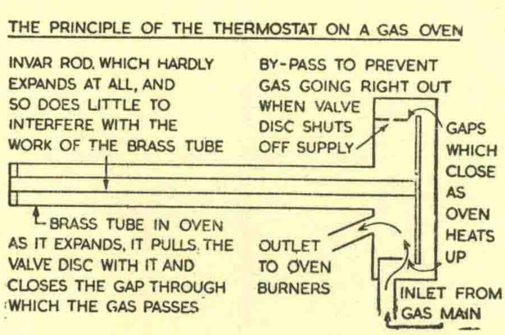
The wheel is to be cooled down through 100° Centigrade. The contraction of the wheel across its diameter:

= $l \times \alpha \times t$
= 100 × ·000026 × 100
= 1 × ·0026 × 100
= 1 × ·26 × 1
= ·26 in.

The tyre should have a diameter of 100 in. −·26 in. = 99·74 in.



An expansion bend to prevent fracture of a long pipe which is sometimes cold and sometimes carries steam.



The thermostat on a gas oven works using the expansion of metals with heat.

SUPERFICIAL EXPANSION

The coefficient of superficial expansion is the increase in area of unit area for a rise in temperature of one degree.

Note: The coefficient of superficial expansion is twice the coefficient of linear expansion.

Example: The coefficient of linear expansion of aluminium is ·000026, so that the coefficient of superficial expansion of aluminium is ·000052.

Formula: where A = original area, t = rise in temperature, and β = coefficient of superficial expansion

Increase in area = A × β × t.

Example: A sheet of brass is 5 sq. ft. in area at 10°C. What will be the area at 310°C? The coefficient of linear expansion of brass = ·000019, therefore the coefficient of superficial expansion = ·000038.

Increase in area = A × β × t
= 5 × ·000038 × 300
= ·057 sq. ft.

Area of heated sheet = 5 sq. ft. + ·057 sq. ft.
= 5·057 sq. ft.

The coefficient of cubical expansion is the increase in volume of unit volume for a rise in temperature of one degree.

Note: For solids the coefficient of cubical expansion is three times the coefficient of linear expension.

Example: The coefficient of cubical expansion of aluminium is 3 × ·000026 = ·000078.

Formula: where V = original volume, t = rise in temperature, and γ = coefficient of cubical expansion

Increase in volume = V × γ × t.

Example: A steel ball has a volume of 100 cu. in. at 15°C. What will be its volume at 615°C?

The coefficient of linear expansion of steel = ·000011, therefore the coefficient of cubical expansion of steel = ·000033.

Increase in volume = V × γ × t
= 100 × ·000033 × 600
= 1·98 cu. in.

Volume at 615°C. = (100 + 1·98) cu. in.
= 101·98 cu. in.

EXPANSION OF LIQUIDS

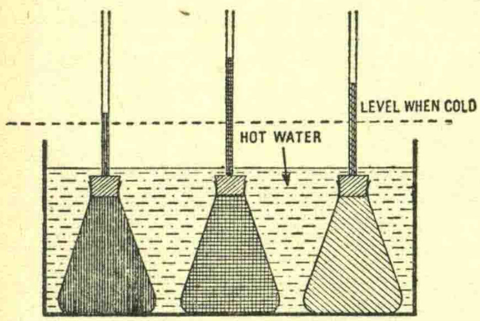
Liquids appear to expand less than they really do, owing to the increase in size of the vessel which contains them.

The apparent coefficient of cubical expansion of a liquid is the one which is measured in a container.

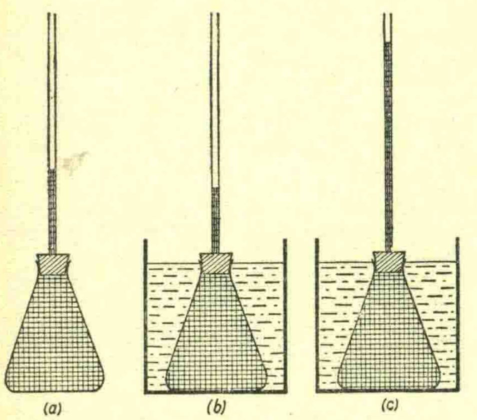
The real coefficient of cubical expansion is greater than this.

The real coefficient of cubical expansion of a liquid is the apparent coefficient of cubical expansion + the coefficient of cubical expansion of the container.

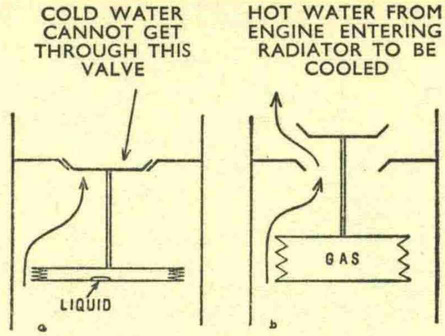
Example: The coefficient of cubical expansion of paraffin oil in a glass vessel is found to be ·0008745. The coefficient of cubical expansion of glass is ·0000255. The real coefficient of cubical expansion of paraffin is ·0008745 + ·0000255= ·0009.



An experiment to show that the expansion of a liquid is great enough to be seen with the naked eye, and to demonstrate the different amounts liquids expand. Three flasks containing different liquids are filled to the same level as shown. Hot water is poured into the trough containing them and the liquids expand different amounts.



An experiment on real and apparent expansion: (a) methylated spirit at room temperature, (b) after a few seconds in hot water the level has dropped because the flask has become warm and expanded before the liquid is heated, and (c) five minutes later in hot water. The spirit is now hot and its expansion is now much greater than that of the flask.



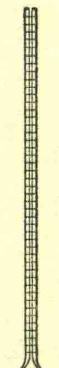
A car radiator thermostat. (a) Engine is cold. The methylated spirit is a liquid and occupies a tiny space. Bellows are closed and valve shut. Water cannot circulate through radiator. (b) Engine is hot. Methylated spirit is a gas and occupies a great space. Bellows are blown out, and valve is opened.

COEFFICIENTS OF CUBICAL EXPANSION OF LIQUIDS, PER CENTIGRADE DEGREE

Methylated spirit	·0011
Turpentine	·0009
Mercury	·00018
Water (5°C.–10°C.)	·00005
(10°C.–20°C.)	·00015
(20°C.–40°C.)	·0003
Paraffin oil	·0009

BOILING POINTS
(under normal air pressure)

Water	100°C.
Methylated spirit	78°C.
Mercury	357°C.
Liquid hydrogen	253°C.
Lead	1,755°C.
Liquid nitrogen	–196°C.
Liquid oxygen	–183°C.



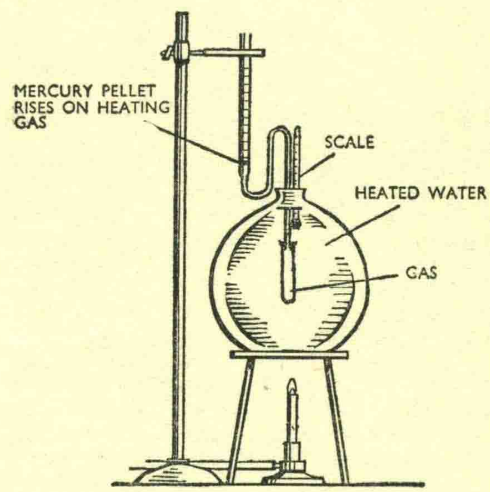
A dilatometer for finding coefficients of cubical expansion of liquids. This one is made of Pyrex, which expands so little that the result is almost a true "real coefficient".

FREEZING POINTS
OR MELTING POINTS

Water	0°C.
Mercury	–39°C.
Methylated spirit	–115°C.
Lead	327°C.
Iron (pure)	1,527°C.
Cast iron (approx.)	1,300°C.
Aluminium	660°C.
Copper	1,083°C.
Oxygen	–219°C.
Platinum	1,773°C.
Tungsten	3,387°C.
Hydrogen	–259°C.

EXPANSION OF GASES

In the expansion of gases with heat another factor has to be considered. This is the pressure of the gas. A given amount of gas may take up a small amount of space at a high pressure, or a large amount at a low pressure. In experiments to show that the volume of a gas has increased it is necessary to ensure that the pressure is the same throughout. The experiment below shows how this may be done.



An experiment on the expansion of gas. A test-tube is filled with gas and into the top is put an S-shaped tube, with a small pellet of mercury in it, supported by the pressure of the gas. The flask is heated with a bunsen burner. As the gas expands with heat it pushes the mercury up the tube, the movement being recorded against a scale. Since the weight of the mercury is constant, so is the pressure of the gas.

UNITS OF HEAT

CALORIES

The calorie is the quantity of heat required to raise the temperature of 1 gramme of water through 1°C. It is also the quantity of heat given out when 1 gramme of water cools through 1°C.

BRITISH THERMAL UNITS

1 B.Th.U. is the quantity of heat required to raise the temperature of 1 lb. of water through 1°F. It is also the quantity of heat given out when 1 lb. of water cools through 1°F.

SPECIFIC HEAT

This is the quantity of heat taken in or given out when a unit mass of a substance changes its temperature by one degree.

Example 1: 1 gm. of water needs 1 calorie to raise its temperature by 1°C.
∴ its specific heat is 1.

Example 2: 1 lb. of water needs 1 B.Th.U. to raise its temperature by 1°F.
∴ its specific heat is 1.

Example 3: 1 gm. of aluminium gives out ·21 calories of heat on cooling through 1°C.
∴ its specific heat is ·21.

SPECIFIC HEATS (calories or B.Th.U.)	
Aluminium	·21
Brass	·09
Copper	·09
Gold	·03
Iron	·10
Lead	·03
Mercury	·03
Solder	·04
Water	1·0
Methylated spirit	·55
Paraffin oil	·51
Sea water	·94
Air	·24
Hydrogen	3·42

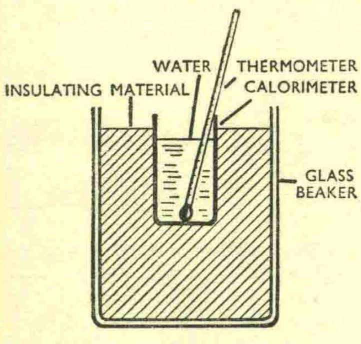
THERMAL CAPACITY

Thermal capacity is the heat required to raise the temperature of an object by one degree. It is mass × specific heat.

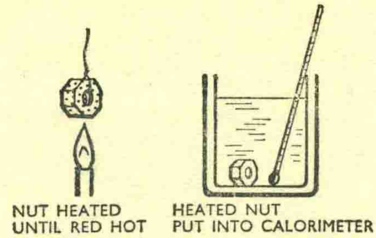
Example: (a) The thermal capacity of 1,000 gm. of copper = 1,000 × ·09 = 90 calories per °C. (b) The thermal capacity of 100 gm. of water = 100 × 1 = 100 calories per °C. (c) The thermal capacity of 10 lb. of lead is 10 × ·03 = ·3 B.Th.U. per °F.

THE METHOD OF MIXTURES

A known mass of one substance, of known temperature and specific heat, is added to a known mass of another substance, also of known temperature. The mixture is stirred, its temperature taken and the unknown specific heat calculated.



A calorimeter of the type used in many heat experiments. It consists of two beakers, one inside the other, with insulating material between. The liquid whose temperature is to be measured is put into the inner beaker and its temperature measured with a thermometer.



An experiment to demonstrate the specific heat of a metal. A metal nut is heated in a bunsen flame until it is red hot. It is then dropped into a calorimeter. The specific heat of the metal can be calculated by the method described on this page (see bottom right).

Equation: Heat lost by one substance = heat gained by the other.
Mass × specific heat × fall in temperature = mass × specific heat × rise in temperature.

Example 1: 20 gm. of metal of specific heat ·1 are heated to 100°C. and dropped into 100 gm. of a liquid at 15°C. The temperature of the mixture is 20°C. What is the specific heat of the liquid?
Heat lost by metal = heat gained by liquid.

$$20 \times {\cdot}1 \times (100 - 20) = 100 \times s \times (20 - 15)$$
$$20 \times {\cdot}1 \times 80 = 100 \times s \times 5$$
$$160 = 500s$$
$$s = \frac{160}{500} = \frac{32}{100} = 0.32$$

Example 2: 100 gm. of a metal at 80°C. are dropped into 250 gm. of water at 20°C. The mixture has a temperature of 30°C. Calculate the specific heat of the metal.
Heat lost by metal = heat gained by water.

$$100 \times s \times (80 - 30) = 250 \times 1 \times (30 - 20)$$
$$10\cancel{0} \times s \times 50 = 25\cancel{0} \times 1 \times 1\cancel{0}$$
$$50s = 25$$
$$s = 0.5$$

HEATS OF COMBUSTION (Amount of heat liberated in burning a known mass of fuel) — Fuel	Heat (in B.Th.U. per lb.)
Bituminous coal	11,000–15,500
Coke	14,500
Lignite	8,000–14,000
Crude oil	20,000
Petrol	20,000
Methane	23,500
Hydrogen	61,000
Alcohol (ethyl.)	12,500
Alcohol (methyl.)	9,500

CALORIFIC VALUE

The calorific value of a solid or a liquid is the amount of heat given out when a unit mass of the fuel is completely burnt. For example, the calorific value of a good-quality coal is about 14,500 B.Th.U. per lb., or about 8,000 calories per gm. For coke the value is about 7,000 calories per gm. (12,600 B.Th.U. per lb.), for wood about 4,000 calories per gm. (7,250 B.Th.U. per lb.) and for paraffin oil 9,800 calories per gm. (17,600 B.Th.U. per lb.).

The calorific value of coal gas is stated in B.Th.U. per cubic foot, e.g. 500 B.Th.U. per cubic foot. Coal gas is sold by the therm—100,000 B.Th.U. of heat.

Example: The December reading of a gas-meter = 20,600 cu. ft.

The September (previous) reading = 18,200 cu. ft.

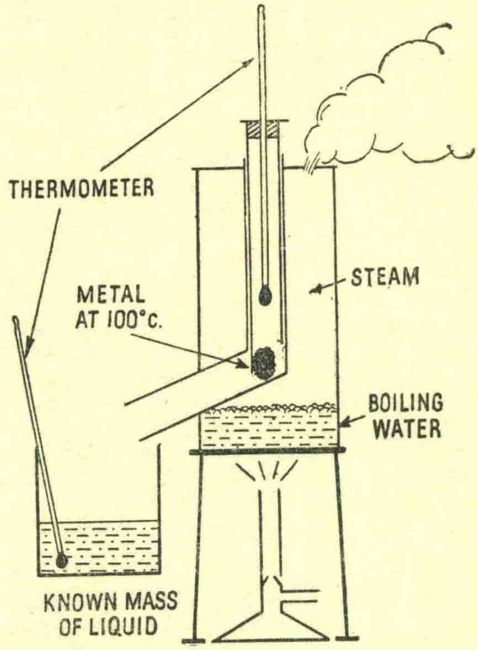
Gas consumed = 2,400 cu. ft.

Calorific value = 500 B.Th.U. per cu. ft. of gas.

Heat supplied on burning gas = 2,400 × 500 B.Th.U.

$$= \frac{2{,}4\cancel{00} \times 5\cancel{00}}{1\cancel{00},\cancel{000}} \text{ therms} = 12 \text{ therms}$$

Cost per therm = 1*s.* 9*d.*
Cost for 12 therms = 12 × 1*s.* 9*d.*
= £1 1*s.* 0*d.*



A specific heat experiment. The apparatus is set up as shown. The inner tube, carrying the thermometer, is a sliding fit inside the outer tube. Metal in the bottom of it is heated to 100°C. by the steam of the boiling water. When it has reached that temperature the sliding tube is pulled up, allowing the metal to fall into the beaker partly filled with liquid. The weight of the metal is known, as is the amount of liquid, and its temperature before and after the metal has been dropped into it. It is therefore possible to calculate the quantity of heat given out by the metal to the liquid, and so the quantity needed to cool 1 gm. of the metal through 1°C. (i.e. its specific heat).

CHANGE OF STATE

Heat has to be supplied to change ice at 0°C. into water at 0°C. As there is no rise in temperature when this heat is supplied, it is known as Latent Heat (of fusion). Heat is also required to change water at 100°C. into steam at 100°C.—latent heat of evaporation.

The latent heat of fusion of ice is 80 calories per gm. (144 B.Th.U. per lb.). The latent heat of evaporation of water = 538 calories per gm. (968 B.Th.U. per lb.).

Calculation 1: 20 gm. of dry ice are added to 100 gm. of water at 22°C. When the ice has melted the temperature of the mixture is 5°C. Calculate the latent heat of ice. L = latent heat of ice.

Heat given out by water cooling from 22°C. to 5°C. = heat gained by ice melting + heat gained by water formed warming from 0°C. to 5°C.

$$
\begin{aligned}
100 \times 1 \times (22 - 5) \text{ calories} &= 20 \times L + 20 \times 1 \times (5 - 0) \text{ calories} \\
100 \times 17 &= 20L + 20 \times 5 \\
1{,}700 &= 20L + 100 \\
1{,}700 - 100 &= 20L \\
1{,}600 &= 20L \\
80 &= L
\end{aligned}
$$

Latent heat of ice = 80 cal. per gm.

Calculation 2: 2 gm. of dry steam at 100°C. are bubbled into 60 gm. of water, raising the temperature from 20°C. to 40°C. Find the latent heat of steam. L = latent heat of steam.

Heat given out by steam condensing + heat given out by water formed cooling from 100°C. to 40°C. = heat gained by original water being warmed from 20°C. to 40°C.

$$
\begin{aligned}
2 \times L + 2 \times 1 \times (100 - 40) &= 60 \times 1 \times (40 - 20) \\
2L + (2 \times 60) &= 60 \times 20 \\
2L + 120 &= 1{,}200 \\
2L &= 1{,}200 - 120 \\
&= 1{,}080 \\
L &= 540
\end{aligned}
$$

The latent heat of steam (also of evaporation of water) = 540 cal. per gm.

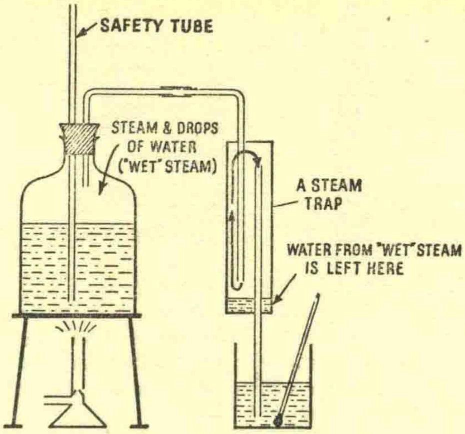
Evaporation can occur at temperatures lower than the boiling point.

Latent heat must be supplied to change a liquid into a gas. If it is not specially supplied, e.g. by a burner, it is taken from the body itself or the surroundings by lowering the temperature.

Example 1: Human beings perspire when too hot, so that the beads of perspiration may evaporate, taking latent heat from the body to cool it.

Example 2: Butter dishes and milk bottles may be kept cool by wrapping them in a damp cloth from which water evaporates, taking the latent heat from the butter dish or milk bottle.

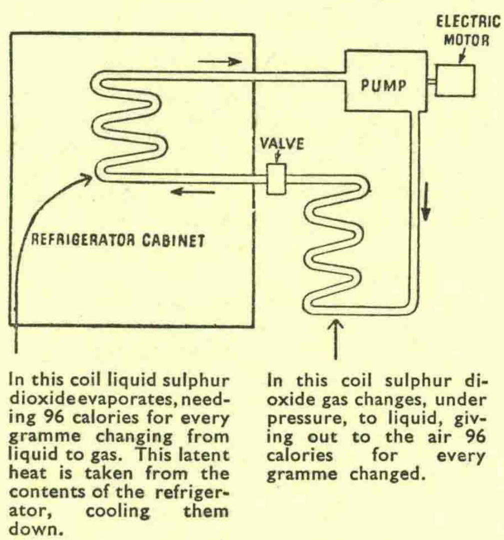
Example 3: It is unwise to keep on clothes which have become wet, because water will evaporate and take the latent heat from the body, thus causing a chill.



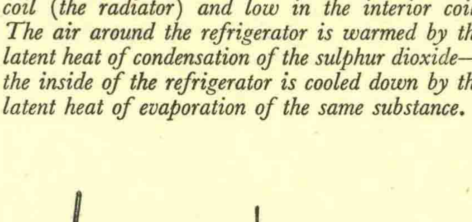
An experiment to find the latent heat of steam. The mass of steam used is found by weighing, before and after the experiment, the vessel in which the steam warms the water.

THE REFRIGERATOR

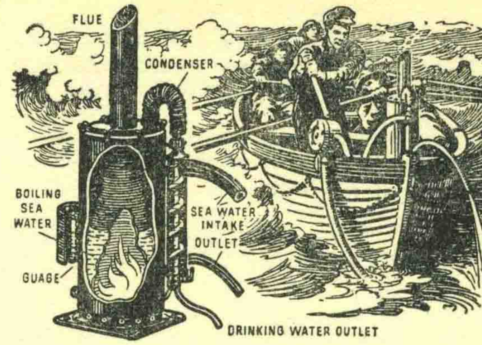
An important use of latent heat is the refrigerator. Sulphur dioxide (latent heat = 96 calories per gm.) is one of the liquids commonly employed.



The valve keeps the pressure high in the exterior coil (the radiator) and low in the interior coil. The air around the refrigerator is warmed by the latent heat of condensation of the sulphur dioxide—the inside of the refrigerator is cooled down by the latent heat of evaporation of the same substance.



A Liebig condenser, used in the laboratory as a means of obtaining distilled water. Boiling coloured water gives off steam, which passes through the tube in the condenser. This is kept cool by the continual passage of cold water from a tap through the outside 'jacket' of the condenser. The distilled water (now pure and colourless) drains off into a flask.

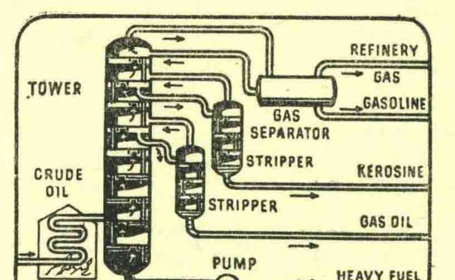


A method of distilling water for drinking. In this type of fresh-water producer, the sea-water is pumped into the apparatus by the lifeboat's bilge pump and heated. The vapour, which is now free from salt, is cooled in the condenser and is converted into water fit for drinking.

DISTILLATION

Distillation provides a method for separating liquids with different boiling points. The liquid of lower boiling point changes to gas, which passes into the condenser, where the cold water jacket changes it back to liquid, which is collected. The liquid of higher boiling point is unchanged. The thermometer reads the temperature of the vapour coming over.

Distillation is used in the oil industry as a method of separating the various kinds of oil from crude mineral oil. When such a mixture is heated carefully, the liquid with the lowest boiling point will evaporate first. This is taken off and condensed. By continuing to heat the mineral oil its temperature will rise until it reaches the boiling point of the next liquid. This is evaporated and then distilled, and so on. In this way many of the liquids in the crude mineral oil can be isolated (see below).



The principle of distillation applied to oil refining. Crude oil is heated carefully, and the oil which has the lowest boiling point vaporises first. The vapour is led away and condensed. By continuing heating, the temperature of the liquid will rise until it reaches the boiling point of the second liquid, which again is vaporised, led off, and condensed. The process is continued until only the heaviest oils with the highest boiling points are left. This process is used in the primary distillation of petroleum oils.

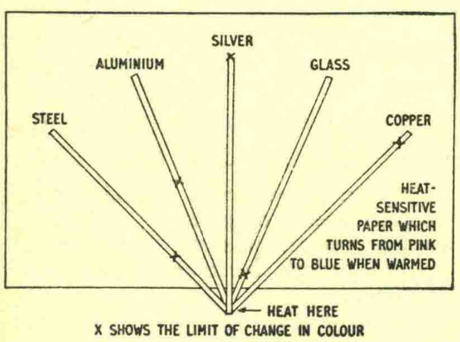
HEAT TRANSFER

The three methods of heat transfer are conduction, convection, and radiation. In any one example, however, it usually happens that more than one of the methods is at work, especially where liquids and gases are involved.

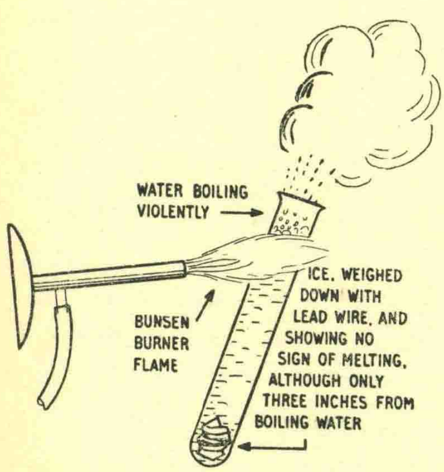
CONDUCTION

Heat passes from point to point in a substance without the substance itself moving. One straightforward example is a poker in a hot fire. The heat travels from one end of the poker to the other, so that if it is left in the fire too long the handle will get so hot that anyone touching it will be burned.

All substances are not good conductors of heat. Silver, copper, iron and aluminium are, while glass, wood, cork and asbestos are not. The experiment with the rods below compares the relative conductivity of various substances in the form of rods.



Five rods of different substances are arranged as in the diagram on a sheet of heat-sensitive paper. Heat is applied at the point where they touch, and the distance the heat has travelled along each rod is shown as it turns the paper blue. Thus the conductivity of the rods may be compared.

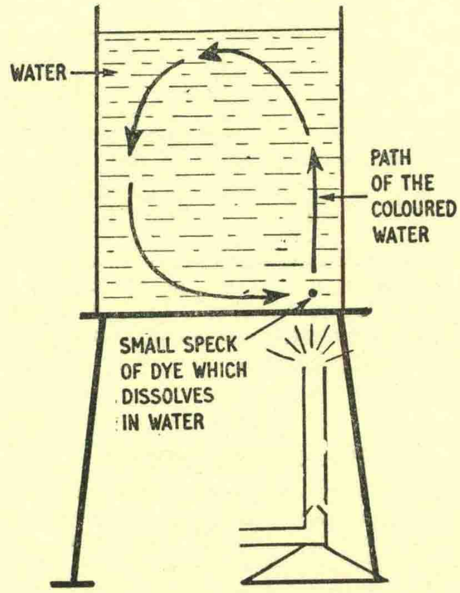


In the experiment above a test tube is filled with water and a piece of ice is weighed down at the bottom with a piece of lead wire. A bunsen burner flame is applied to the top of the test tube, making the water there boil. In the same tube is both ice and boiling water, thus showing that water is a relatively poor conductor of heat.

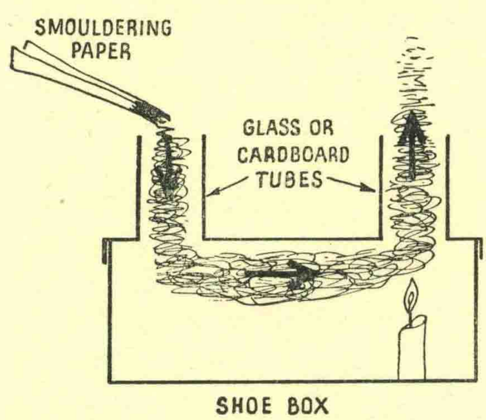
CONVECTION

This is the movement of heat through the setting up of currents in a liquid or gas, owing to the expansion and consequent decrease in density of the substance in contact with the source of heat.

The best everyday examples of the application of convection currents are in the ventilation of rooms, the supply of air to fireplaces and boilers, and in domestic hot-water systems and the cooling of motor-car engines.



An experiment to demonstrate convection currents in a liquid. Water is heated in a beaker and a small crystal of dye is dropped in. As it begins to dissolve it colours the water and traces out the path of the convection currents.



Convection currents in gases are demonstrated by the experiment above. The smoke from smouldering paper (heavier than air) goes down the tube on the left. Over the candle flame it is heated, expands, becomes less dense (and lighter than air), and goes out of the tube on the right.

RADIATION

Radiation is the method of heat transfer where heat waves travel through space rather like light waves, and heat another object which may be some distance away. Heat waves can travel through empty space, as, for example, happens with the heat we receive from the sun. Cool bodies radiate very little heat, intensely hot bodies a great deal.

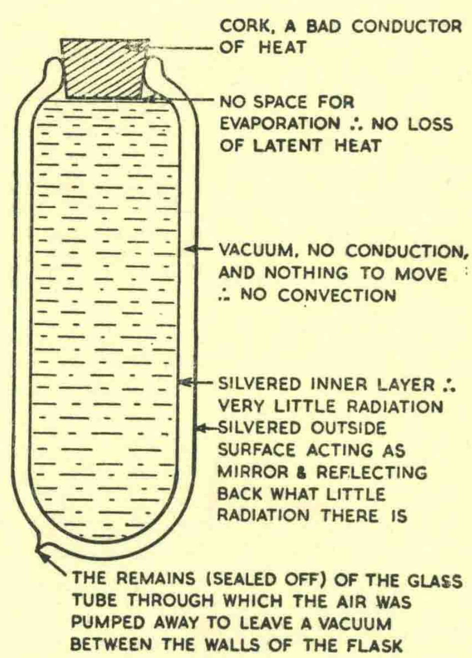
The heat radiated by a body is proportional to the fourth power of the Absolute temperature. For example, the heat radiated by a body at 2,730°A. is 10 × 10 × 10 × 10 times that radiated at 273°A. (0°C.), i.e. 10,000 times as much. Black surfaces radiate more heat than white ones, and dull surfaces radiate heat better than highly polished ones. Radiated heat is absorbed best by dull black surfaces and least by white and highly polished ones.

The polished reflector behind an electric heating element reflects radiated heat into a room just as the reflector of a searchlight reflects a beam of light. In countries where there is much sunshine steam may be raised by reflecting the sun's rays on to a boiler by means of huge mirrors.

INSULATION

We choose aluminium, copper, and iron for our kettles and saucepans because they conduct heat well. We like eiderdowns (loosely packed with big feathers) and fur coats in winter because they are bad conductors of heat—in other words, good insulators. They prevent heat from being wasted.

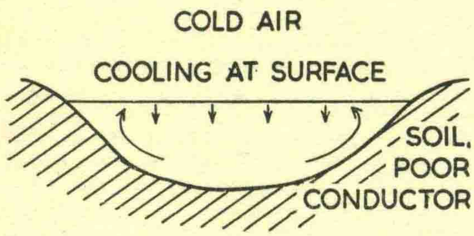
Cavity walls—two separate brick walls with an air space between—are good insulators and allow a house to be cool in summer (preventing heat from coming indoors) and to be warm in winter (preventing heat from escaping outside). Fibreglass is another good insulator, and mats of this material laid on a ceiling lead to a further improvement in comfort. All these insulators are made more effective because they combine their own properties with those of the air in them. Air is one of the best insulators of all.



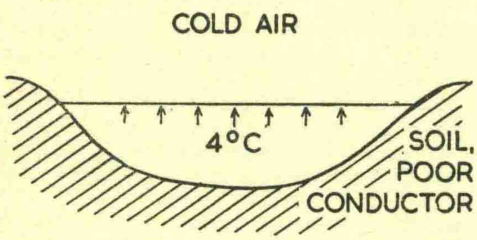
A vacuum flask will keep tea or soup hot for at least twenty-four hours. Since it is just as difficult for heat to pass into the flask from the outside as it is for heat to be lost from the inside, the vacuum flask may be used to keep iced drinks cold. This it will do for many days. In the case of the iced drink the difference in temperature between the contents and the outside air is much less than that of the hot drink, hence the longer period of time for which the flask is effective.

THE BEHAVIOUR OF WATER

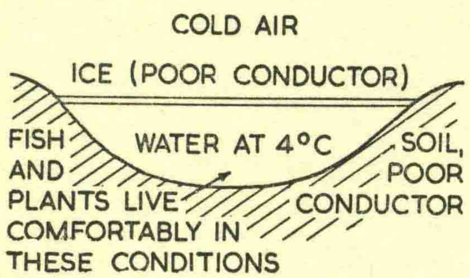
Water does not behave quite like other liquids when subjected to heat or cold. Below is the sequence of freezing over of a pond, which results in a thin layer of ice over the top with a moderately warm volume of water below it.



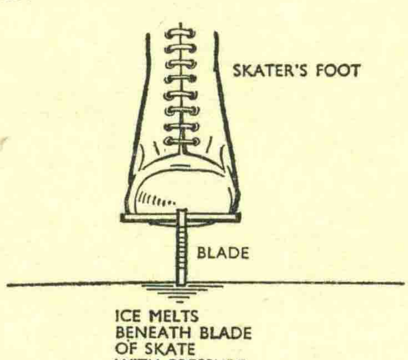
Stage one: As water cools to about 4° Centigrade it contracts, becomes denser, and the level sinks. The water from the bottom is forced up by the descending cold water and is cooled. All the water is cooled down rapidly.



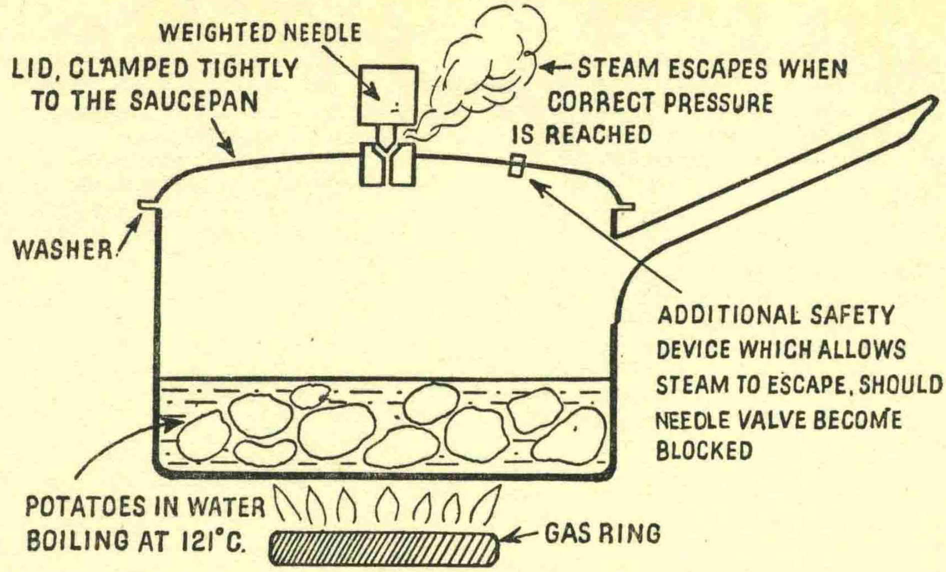
Stage two: When all the water is at 4°C. it begins to expand, becoming less dense. The water on top stays there and protects that underneath from contact with the cold air.



Stage three: The air above the pond is considerably colder than 0°C. (freezing point). The ice on the top of the pond is a poor conductor of heat, and prevents the water below it from becoming any colder.



Skating. It is interesting to note that but for the peculiar behaviour of water the ice would form at the bottom of the pond instead of at the top. The reason why it is possible to skate on the ice is that the pressure of the skater melts the ice below the blade of the skate. Water under great pressure freezes at a lower temperature than 0°C. The skater is actually travelling along on water, not ice, though it will freeze again almost immediately after the skater has passed.



One application of the higher boiling point of water with increased pressure occurs in the domestic pressure cooker, where the sealed container allows twice the pressure of the ordinary atmosphere to be attained. In this way food can be cooked at about 121°C. instead of the usual 100°C., the usual boiling point. With the greater heat the food is cooked far more quickly. A valve in the lid prevents the pressure in the cooker from becoming too great.

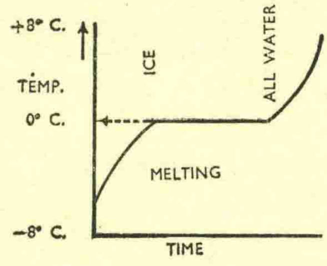
CHANGES OF VOLUME

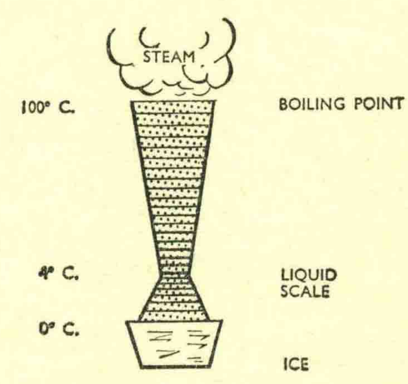
The diagram and graph below show how the volume of water changes with variations in temperature. Water contracts when cooled. Shortly above freezing point, however, it starts to expand. On turning to ice it expands still more, though later it contracts again.

Note: Because of the effect of latent heat, cooling water does not get any colder until all of it has turned to ice. Boiling water does not get any hotter until it has all turned to steam. Only then does the rise or fall in temperature continue.

THE EFFECT OF AIR PRESSURE ON THE BOILING POINT OF WATER

Air pressure in atmospheres (i.e. compared with normal air pressure on the earth's surface)	Boiling point of water in degrees Centigrade
Normal	100
Half	81
Quarter	65
Twice	121
Four times	145
Eight times	171

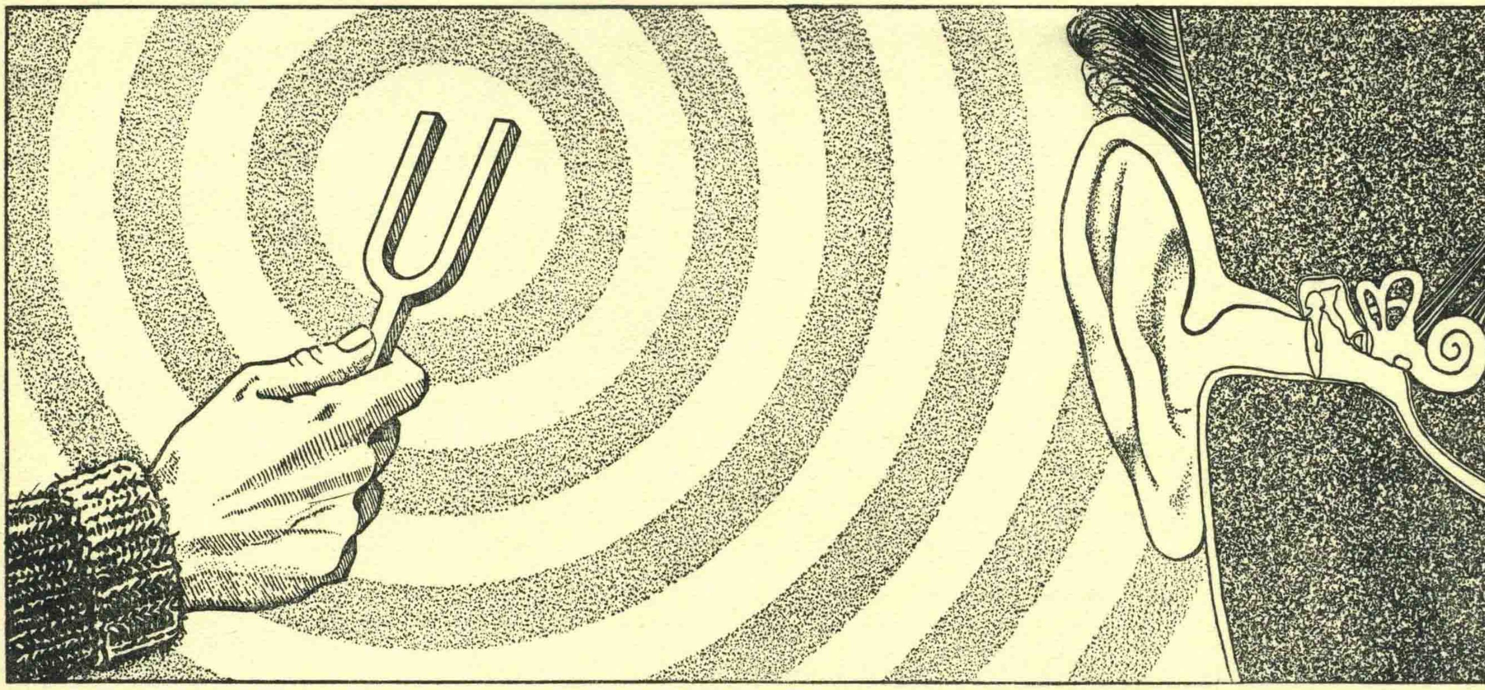




SOME FREEZING TEMPERATURES

Mixture (parts by weight)	Freezing temperature (°C.)
Melting ice or snow	0
2 of crushed ice, 1 of common salt	−18
3 of crushed ice, 4 of calcium chloride crystals	−48
1 of ammonium nitrate crystals, 1 of ice	−15

THE SCIENCE OF SOUND



When a tuning fork is struck, its vibrations set up sound waves in the air which travel outwards in all directions. The sound waves enter the ear, and vibrate the ear drums. The vibrations are transmitted to nerve-endings by tiny bones acting as levers. The nerves carry the appropriate message to the brain, where it is interpreted as sound.

Sound is important to us in three main ways. First, it provides us with a means of communication. If we were not able to convey our ideas by the spoken word we should be very much handicapped indeed. Soldiers on parade would not be able to respond to the commands of their sergeant-major. Pupils in their classrooms would no longer be able to receive the help of their masters, except to a very limited extent. There is practically no end to the list of examples.

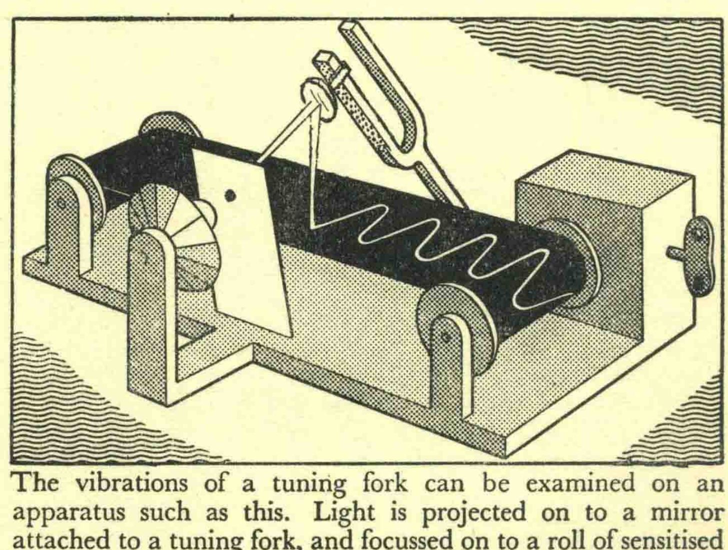
Secondly, sound is useful as a warning. The noise of an oncoming motor car warns us not to step off the pavement. A knock on the door tells us that someone wishes to enter. After the event, a crash of teacups tells us that mother has tripped over the carpet in the kitchen!

Lastly, sound gives us a great deal of comfort and pleasure. In the concert hall, the opera house and the cinema we gain much satisfaction and enjoyment from the voices and music of the performers. The familiar voices of our friends and relations are generally a great source of pleasure to us.

We have become so used to the sounds around us that we should feel very ill at ease without them. Complete silence, however, is rarely found, even in the areas most remote from civilisation.

Sound is the result of movement, even though all movement does not necessarily produce it. The wind makes a rustle of the leaves. Without the wind there would be no sound there. A violin is silent until a bow is drawn across the strings. When the bow is removed, the note dies away, and finally all is still.

All the sounds we hear are conveyed to our ears by means of vibrations in the air It is not possible to transmit sound through a vacuum, so without air we should not hear any sound. Sound can, however, be transmitted through liquids and solids.

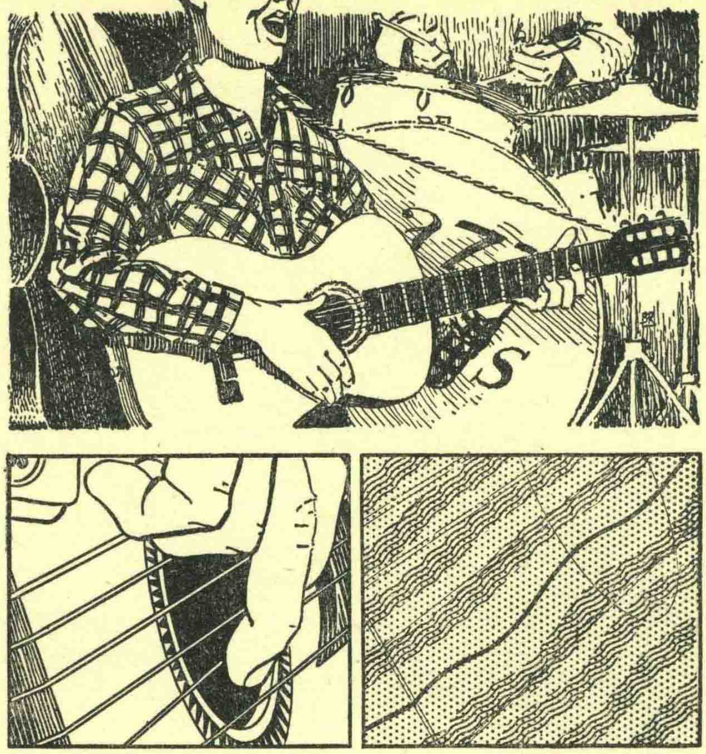


The vibrations of a tuning fork can be examined on an apparatus such as this. Light is projected on to a mirror attached to a tuning fork, and focussed on to a roll of sensitised film passing at a constant speed below. As the fork vibrates the light shows up the movement as a wavy line.

Waves and Vibrations

Sound waves are a series of push-and-pull (longitudinal) impulses carried by the air. They act in much the same way as the ripples in a pond after a stone has been dropped into it. The air in contact with a source of vibration (e.g. a guitar string) is alternately compressed and expanded. This takes place rapidly, and is in fact a vibration. Like the ripples in the pond the vibrations at the source build up into pressure waves which travel outwards in all directions.

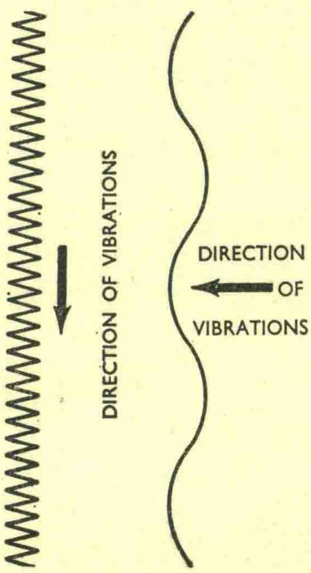
The pressure waves convey all sounds through the air. The pitch of any one sound is decided by how frequently the air is vibrated. This in turn affects the wave-length, the distance from crest to crest of the pressure waves. Thus the low notes of a bass singer vibrate the air less frequently and have a longer wave-length than the high notes of a soprano.



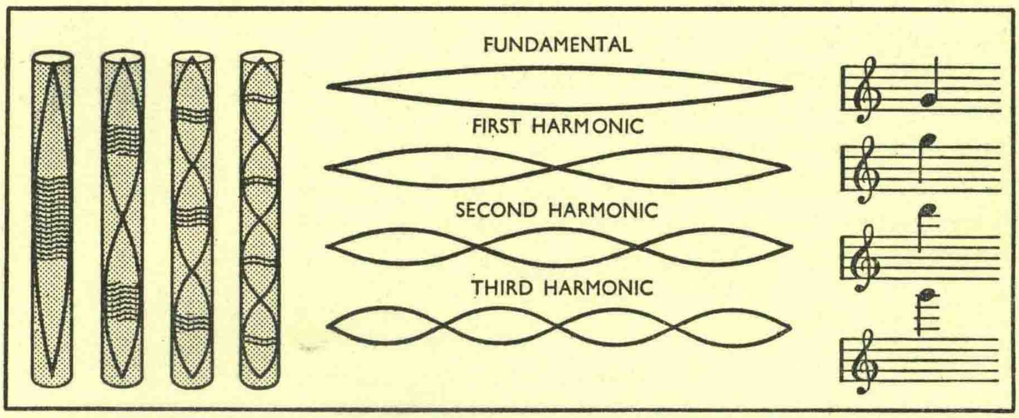
The jazz guitarist in the picture provides a good illustration of how sound waves work. He plucks the string of his instrument, and the string vibrates from side to side in transverse waves. The vibrations set up longitudinal waves in the nearby air, at the same rhythm or frequency as the string. Additional "strength" is given to the waves by the resonance of the instrument itself.

The loudness of a sound is determined by how strongly the air vibrates. The report of a shot gun fired close at hand, for example, produces very much more powerful sound waves than the tinkle of a distant cow bell. Of course the further away the source of noise, the fainter it is. The waves from a shot gun fired five miles away are considerably less powerful than they would be if it were fired nearby. In fact we should have difficulty in picking them up at all.

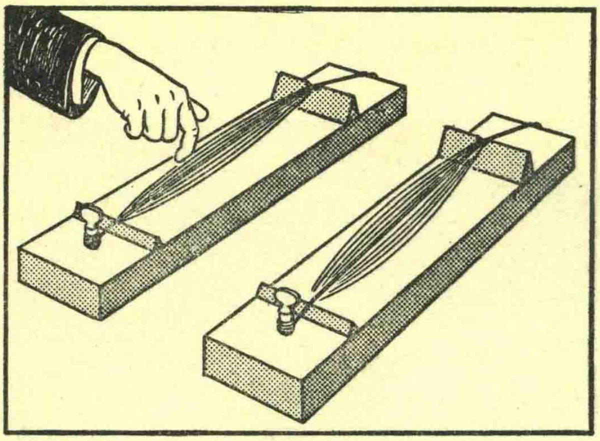
We rarely hear a pure note. Most sounds, even those produced by musical instruments, are made up of several harmonising notes. The diagram below shows how the fundamental note has a series of harmonics. In terms of wave-length the harmonics are related mathematically to the fundamental note, i.e. they have wave-length one half, one third, one quarter of the fundamental, and so on. When a series of notes are played together, and their wave-lengths are not related to each other mathematically, the result is a discord, an unpleasant sound.



Sound is transmitted through air by means of longitudinal waves. This means that pressure from the sound source is applied at short intervals, forcing the air to pile up in waves. When stringed instruments are plucked or bowed, the strings vibrate in transverse waves, i.e. across the line of stretching. The diagram on the left represents longitudinal waves; that on the right represents transverse waves, like those occurring in air.



Each fundamental (basic) note has many harmonics which produce a melodious effect when played with it. The wave-length of the fundamental is shown diagrammatically as though produced by a vibrating unstopped string, and an organ pipe. Musically the harmonics are a third, a fifth, and a seventh of an octave above it.



If two strings are tuned to the same note, and one is plucked, the other vibrates as well. The sound waves produce a *sympathetic vibration.* Similarly a singer may smash a glass by vibration if he sings to the same note as the "ring" of the glass.

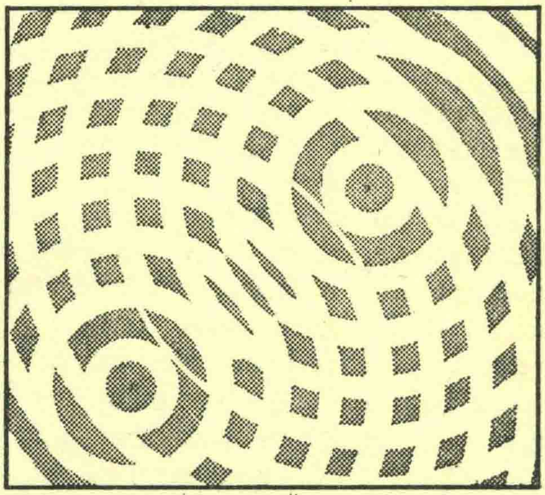
The Behaviour of Waves

Some applications of the behaviour of sound waves are found in the planning of public buildings such as theatres and concert halls. Every member of an audience must be able to hear perfectly what is said or sung on the platform. Only by experiment and a knowledge of sound waves can this be achieved satisfactorily. The study of this subject is called acoustics.

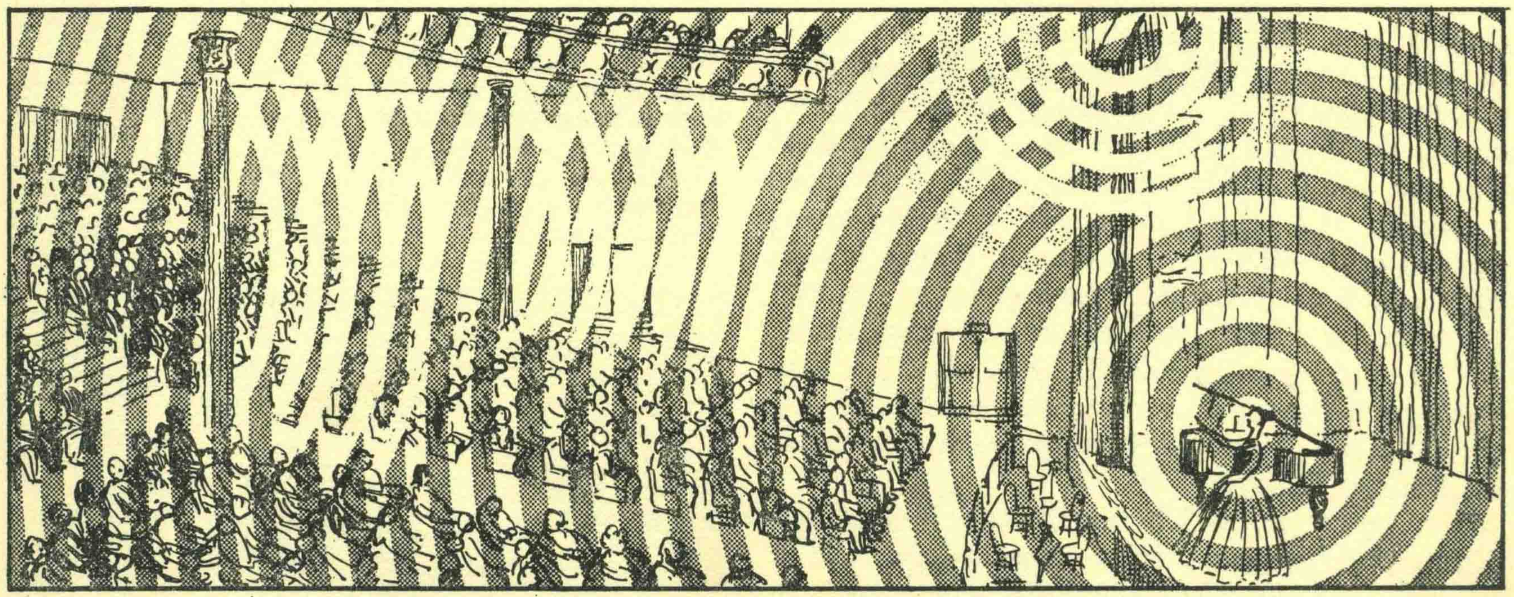
Perhaps the most important requirement is that the sound should be distributed evenly over the air-space. In general this means that the hall or theatre should be clear, with no nooks and alcoves likely to mask the sound. Large unbroken curved surfaces tend to reflect and focus sound in certain areas, leaving others "dead". Hard and shiny surfaces, such as pillars and doors, tend to reflect the sound waves and cause echoes. The listener will hear both the original wave and, a little later, the echo. The effect will be a blurred noise. This principle is called "interference."

Architects planning large halls try to avoid having large areas of smooth surfaces. In modern structures the walls are often covered with tiles made of felt or fibre-glass which absorb sounds rather than reflect them. Theatre seats are covered with velvet or cloth, and this, together with the clothes of the audience, helps to keep down echoes. Theatres are built in such a way that sound travels best from the stage forwards. This is helped by the proscenium arch over the stage and the scenery, which together help to "funnel out" the sound.

The importance of sympathetic vibration (see top left) can hardly be overstated. While architects choose materials for their halls which will not vibrate in sympathy with the voices or music of the players on the stage, makers of musical instruments ensure that their products *will* resound and "magnify" the vibrations.

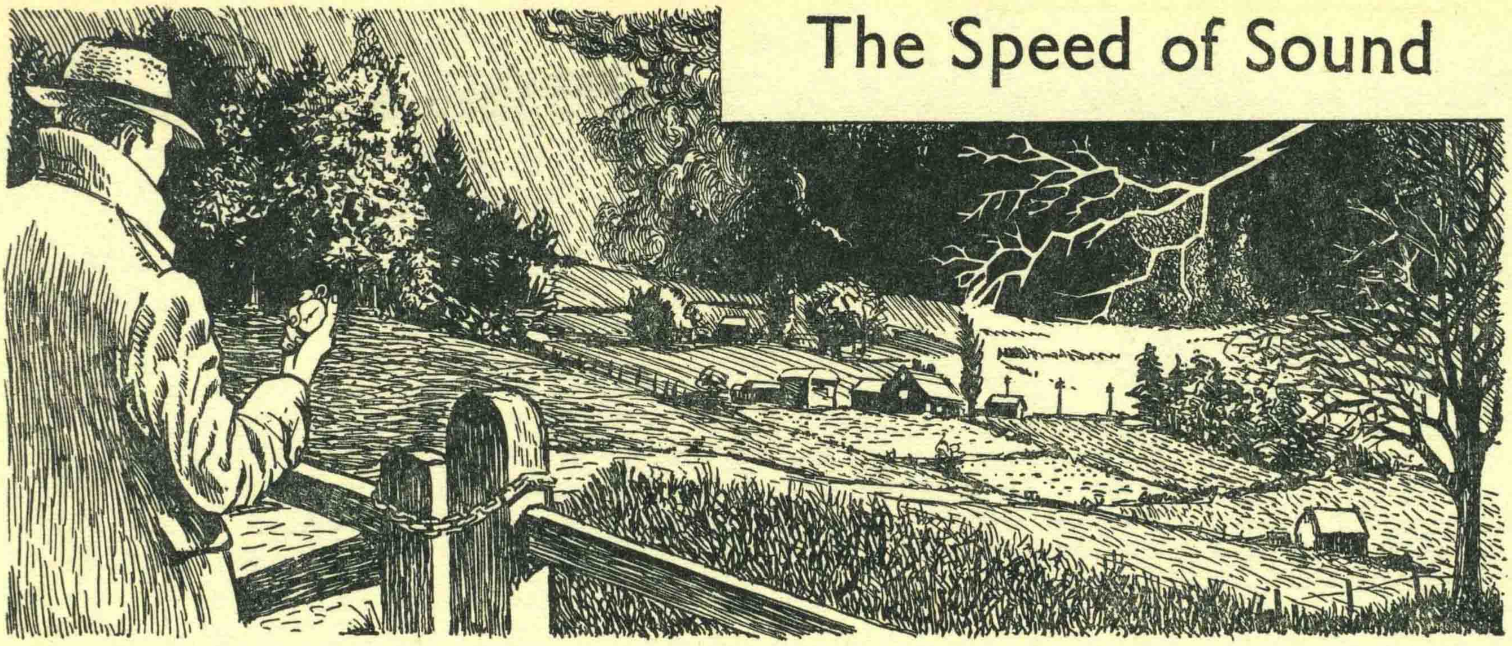


The pattern of interfering sound waves produced from two sources is like that of the ripples of two stones dropped into water. The ripples from each interfere with those from the other.



The diagram shows how the sound waves in a concert hall spread out from the singer over the audience. Where hard shiny objects, such as pillars, intervene, echoes are produced which can spoil the performance for listeners round them. To solve their problems, architects often make a scale model of a hall they have planned and fill it with water. By agitating the water at the point where a performer would stand, the ripples show how sound waves would behave in the full-size hall.

The Speed of Sound

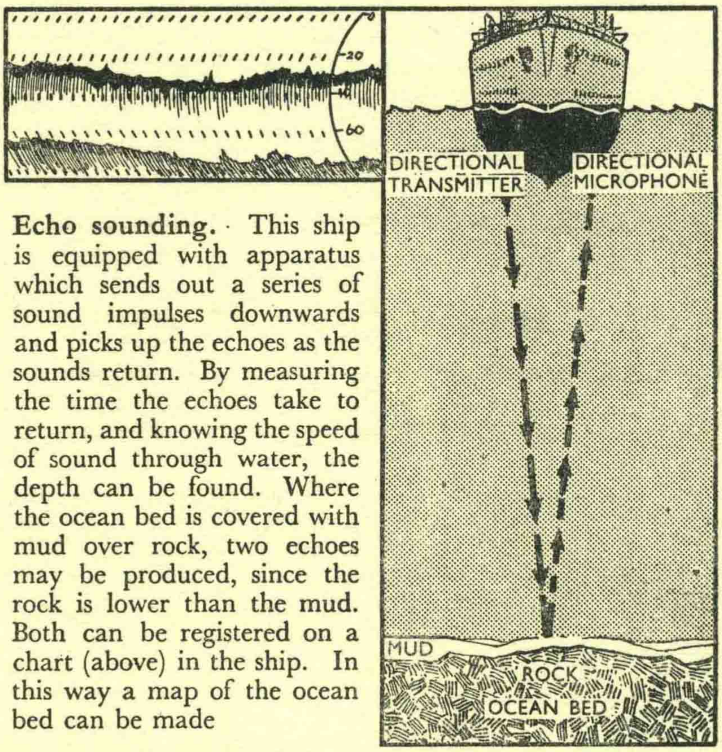


It is possible to work out the distance away of a thunderstorm by timing the interval between seeing the flash and hearing the thunder crack. Light travels at 186,000 miles a second and the flash is seen the instant the lightning occurs. The speed of sound is about 1,120 feet per second (about 1/5 of a mile per second). If the interval between flash and sound is five seconds, then the storm is a mile away.

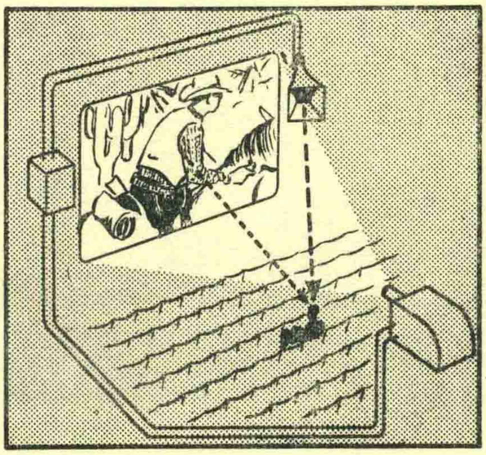
Since sound waves travel outwards from their source, there is a time lag between the moment when a noise is produced and the moment when it is heard some distance away. The velocity of sound through air is approximately seven hundred and sixty miles per hour, though this varies slightly with differences in temperature, altitude, and with movement of the air (wind).

An interesting effect occurs when the source of sound is moving. The whistle of an express train appears to change its note as it passes an observer standing by the side of the railway track. At first, when the train is approaching, the note rises steadily and then, having passed by, the note suddenly drops. This is explained by the fact that the speed of the approaching train steadily increases the frequency of the waves heard by the observer, and thus raises the pitch of the note. For a fraction of a second the whistle is in the same position as the observer, and the note is then heard as it would be if a train were stationary. When the train has passed, the frequency of waves heard by the observer is lowered (i.e. the vibrations are slower and the pitch of the note is lowered) as the train moves away. This process is known as the Doppler Effect.

The speed at which sound travels through different substances varies considerably. The scientist Sir Isaac Newton found that the velocity of sound in a material varies with its "elasticity." In the case of a gas this depends on both density and pressure.

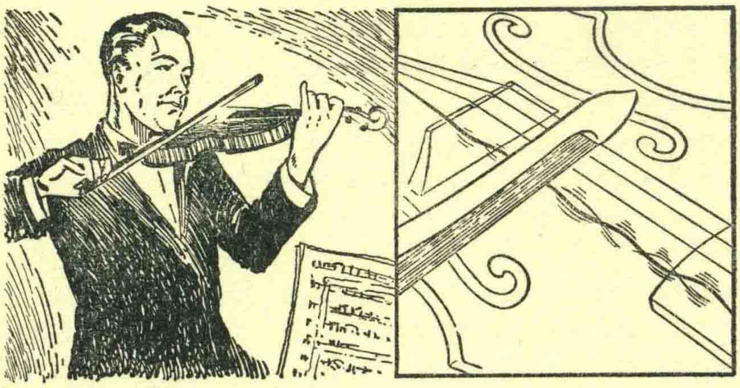


Echo sounding. This ship is equipped with apparatus which sends out a series of sound impulses downwards and picks up the echoes as the sounds return. By measuring the time the echoes take to return, and knowing the speed of sound through water, the depth can be found. Where the ocean bed is covered with mud over rock, two echoes may be produced, since the rock is lower than the mud. Both can be registered on a chart (above) in the ship. In this way a map of the ocean bed can be made

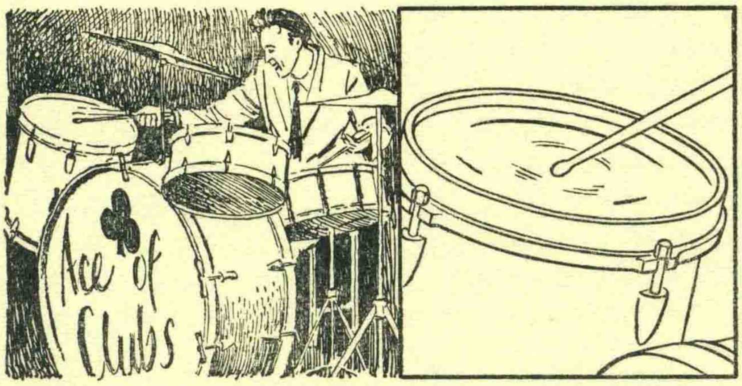


At the cinema, sound and picture are projected at practically the same time. The audience do not always receive them together. At the back they may notice a gap between sound and picture, due to the difference in speeds between sound and light.

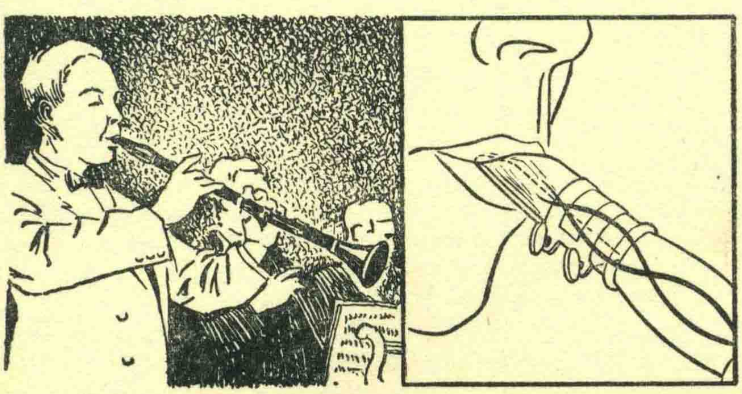
Instruments for Making Music



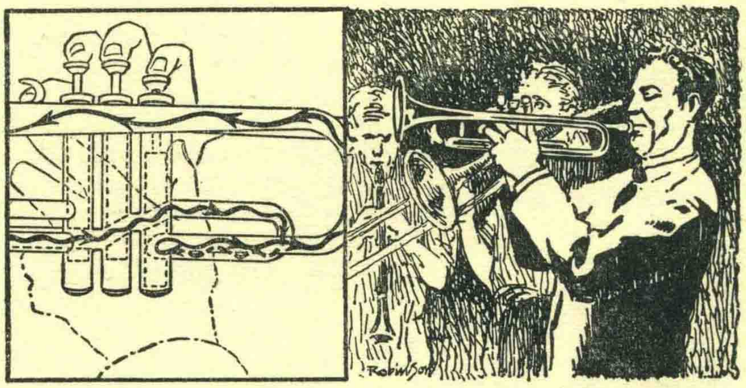
The trumpet is one of the simplest of the brass wind instruments which include the trombone, horn, tuba, bugle, and cornet. The air is blown through the mouthpiece where it is vibrated with the lips. The note varies with the type of vibration and the length of pipe. In an orchestral trumpet the latter (with its column of air) can be varied by pressing the keys on top. The end of the trumpet widens out into a "bell" to make the notes resound. The usual orchestral trumpets are either C or B flat. A C trumpet has a pipe four feet long. In the case of the trombone, the length of the pipe is varied by extending part of it on a system of sliders. Other brass wind instruments without keys are the bugle and the hunting horn.



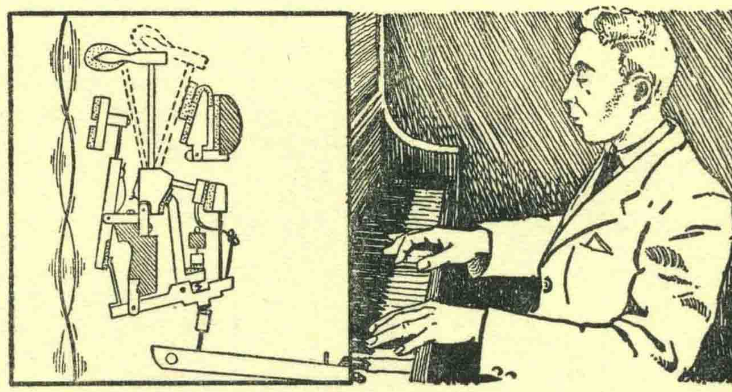
Perhaps the most common of our musical instruments, the pianoforte, is played by striking keys which control hammers in the mechanism. The hammers flick against metal strings tuned to the appropriate pitch. These vibrate and the resulting notes resound in the metal frame and the wooden cabinet. Tone can be adjusted by means of foot pedals controlling pads pressed against the strings. The so-called loud pedal releases all the pads so that any strings which might vibrate do so (sympathetic vibration). The so-called soft pedal reduces the distance through which the piano hammers are moved, giving a softer sound. In upright pianos the strings are set vertically, in grand pianos horizontally.



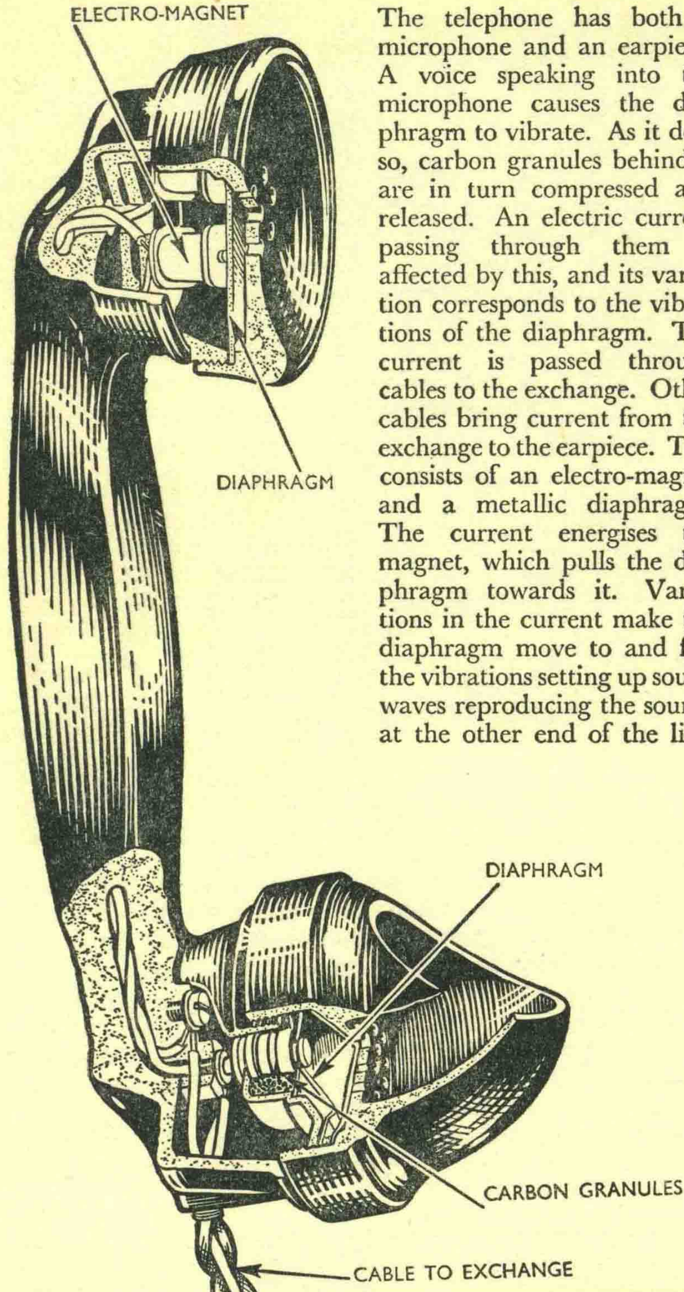
The notes of the violin are produced by the friction of a bow of resined horse hair against strings stretched tightly across the instrument. The strings can also be plucked like a guitar. They are made of catgut and stretched so that they vibrate to the pitch of G, D, A, and E. The other notes are produced by *stopping*, that is shortening them by pressing them with a finger at various points so that only part of them can vibrate. The shorter the string of a given tension, the higher the note. The viola, cello, and double bass are played in a similar way, all of them having a lower register than the violin. In the "belly" of these instruments is a soundpost which helps their resonance.



The drum is a percussion instrument, where the sound is made by a blow. The bass and side drums shown are double-sided, covered with two tightly stretched skins with air between. When one side is struck a noise is caused by the vibrations of the skin and the air around it. The more tightly stretched the skin, the higher the pitch. The tension can be adjusted by screws round the edges of the drum. For orchestral uses the timpano, or kettle drum, is usually preferred. It has one skin, stretched over a deep metal cup. Varying kinds of tone can be obtained by using different kinds of drumsticks. The timpano is the only type of drum which can easily be tuned to different notes.



The clarinet, like the bassoon, the saxophone, and the oboe, is a reed instrument. Air is blown through the mouthpiece over a single cane reed which vibrates. The vibrating air passes through the main stem of the pipe which is in effect shortened or lengthened by holes in the side which may be open or closed. For convenience keys are fitted, sprung so that the holes are covered until they are pressed. Clarinets are usually made in D, E flat, F and A. They are described as woodwind instruments. Of the other instruments in the same group the piccolo and the transverse flute are played crosswise, and air is blown *across* a hole in the end. The oboe, the cor anglais and the bassoon use a double reed instead of a single one.



The telephone has both a microphone and an earpiece. A voice speaking into the microphone causes the diaphragm to vibrate. As it does so, carbon granules behind it are in turn compressed and released. An electric current passing through them is affected by this, and its variation corresponds to the vibrations of the diaphragm. The current is passed through cables to the exchange. Other cables bring current from the exchange to the earpiece. This consists of an electro-magnet and a metallic diaphragm. The current energises the magnet, which pulls the diaphragm towards it. Variations in the current make the diaphragm move to and fro, the vibrations setting up sound waves reproducing the sounds at the other end of the line.

Sound Reproduction

Some of the great triumphs of science in the last hundred years have been concerned with the reproduction of sound. It can now be transmitted over long distances by radio or telephone, or "stored" for future reference on a gramophone record or magnetic tape.

Electrical methods of sound reproduction are based on the idea that the vibrations in the air can be converted into electrical pulses by a microphone. When the pulses have been increased in strength by an amplifier, they can be fed into a loudspeaker which has a plate or diaphragm able to vibrate and reproduce sounds which correspond closely to the original ones.

A comparatively new aspect of the subject is the recording and reproduction of sound using stereophonic methods. Simply put, this means sound is heard from many directions at the same time. When we go to an orchestral concert, for example, we hear the violins on our left (usually), and the cellos and bases on our right. Our ears hear the sounds in slightly different strengths, and our brain works out the direction from which they came, balancing them. A gramophone playing the same symphony produces the sound from only one place, the single loudspeaker. If, however, two or more microphones are used in recording, placed, say, to the right and left of the orchestra, and the sounds are recorded on two records, or twin tracks, the result when played back over two loudspeakers to the right and left of the listener will be much more life-like and satisfying.

Methods of sound reproduction. 1. The gramophone needle follows the sound track of the record as it spins on the turntable. Minute waves in the track are transferred to the sound head as vibrations. A membrane attached to the needle turns the vibrations into sounds, which are amplified in a funnel. 2. A tape recorder uses magnetic tape. As the tape runs through, magnetic charges on it induce electrical impulses in the sound head. These are amplified and fed to the loudspeaker. 3. In a film projector the sound track appears on the film as a series of lines and marks running down by the side of the pictures. A light shines through the sound track on to a photo-electric cell. Changes in the light caused by the track are converted into electrical impulses which are amplified and fed to the loudspeakers.

Glossary

Audibility The rates of vibration which produce the sensation of sound vary from person to person, and, for the same person, with age. Some people are oblivious to the high-pitched whine of a mosquito's wings, while others are infuriated by it.

Average values:

Lower limit of audibility: 20 vibrations per second.
Upper limit of audibility: 25,000 vibrations per second.

Animals clearly have different limits: there is a special high-pitched whistle used for calling dogs at night quite inaudible to human beings.

Beat Notes When two different notes are sounded together, the combined note is found to increase to a maximum intensity, die away to a minimum, rise again to a maximum and so on at a regular frequency. (Twin-engined aircraft often give this effect when their engines are not running at the same speed.)

For example, if notes of frequencies 500 and 499 c.p.s. are sounding simultaneously there will be one loud period (or beat) each second, because $500-499=1$. If the notes have frequencies of 250 and 250·5, there will be half a beat per second (i.e. 1 beat in 2 sec.) because $250.5-250=\cdot5$. Number of beats per second = difference between frequencies in cycles per second.

Behaviour of Sound Sound cannot travel through empty space (vacuum). The ringing of a bell can be heard through a glass cover until the air is pumped out. The sound is heard again as the air is allowed to return. Sound normally travels through the air to our ears.

Sound also travels through solids. The ticking of a watch resting on a table can be heard by placing the ear against the table top.

Sound also travels through liquids. Tapping on the side of a bath is heard very clearly when both ears are under the water.

Sound can be transmitted by the human skull. The tapping of a pencil on the teeth and the ticking of a watch held against the forehead are clearly audible even with cotton wool in the ears.

Concert Pitch Almost all ears are offended by notes played out of tune, i.e. with the wrong relationship to others. The majority of listeners do not worry about the actual frequencies used (i.e. the "key" of the music) so long as the relationship between the notes is correct. Thus, until 1929, military band instruments were tuned to a higher key than those of an orchestra, so they could never play together. By international agreement, in correct Concert Pitch, the A above middle C of the piano has a frequency of exactly 440 cycles per sec. (c.p.s.).

Chromatic Scale The Chromatic Scale in use today is an equi-tempered scale. It has 13 notes in the octave and scale, taking any note as Doh, may be played and found to be pleasing. An example is given above.

Chromatic Scale of the Octave above "middle C" (concert pitch).

Note	*Frequency*
C	261.5
D♭	277
D	293
E♭	311
E	329.5
F	349
G♭	370
G	392
A♭	415
A	440
B♭	466
B	494
C	523

Decibel The human ear is a poor judge of loudness. Sounds are often measured in terms of the energy required to produce them. If there is an increase in intensity of 10 times, there is said to be a "gain of 1 bel". A smaller and more convenient unit is the "decibel", a tenth of a bel.

If there is a "gain of 1 decibel" in intensity, the sound is 1.259 times as loud as before. $(1.259)^{10}=10$. A gain of 5 decibels means an increase of $(1.259)^5=$ approx. 3.2 times as loud, while a gain of 50 decibels means an increase of $(1{\cdot}259)^{50}=10^5$ or 100,000 times as loud.

The decibel scale is thus a scale in which enormous differences in loudness can be expressed by means of small numbers.

The zero for the decibel scale of intensity is the faintest sound of frequency 1,000 c.p.s. which can be detected by the human ear.

Döppler Effect The whistle of a locomotive rushing past a station platform falls suddenly in pitch as it passes. The same effect is noticed with the whine of a fast motor cycle or car. The frequency heard is greater than the real frequency as the sound approaches and lower than the real frequency as the source of sound recedes.

Consider an engine whistle of frequency 560 c.p.s. approaching at 60 m.p.h. (88 ft. per sec.). Imagine the engine is still, and we are moving towards it at 88 ft. per sec. —the effect is the same. If sound travels at 1,120 ft. per sec. the wavelength of the sound in air$=\frac{v}{n}=\frac{1{,}120}{560}=2$ ft.

If we stand still, 560 of these waves pass us in a second, therefore we hear the note of frequency 560.

But in moving 88 ft. towards the engine in a second we pass through 44 extra of these waves spaced 2 ft. apart, i.e. we receive $560+44$ in all$=604$. We thus hear the note as 604 c.p.s. instead of 560 c.p.s. By similar reasoning, the note heard as the whistle goes away from us is $560-44=516$ c.p.s.

Echoes When a sound wave leaves its source and is reflected back by an obstruction (e.g. a cliff, a building) the result is an echo. The time between the sound being produced and heard again as an echo is the time taken for sound to perform a double journey out to the obstruction and back again. Thus a cliff one mile away would produce an echo of a gun-shot 10 sec. later (10 sec. being the time required for sound to travel two miles in air).

Echoes are often heard (without our realising it) in theatres, concert halls, churches and other large buildings. The speaker's words may be heard again a fraction of a second after first hearing them, sometimes making it very difficult for an audience to understand one word while it is accompanied by the echo of the previous word. A hall in which it is difficult to hear because of echoes is said to have bad "acoustics". Nowadays the acoustics of a building are tested on small models, which can be altered at little cost, before the construction of the building itself is commenced.

Harmonics See Overtones in stringed instruments.

Hearing The sensation of sound is the result of stimulating, by means of vibration, a series of nerve-endings, housed in the skull. These effects are interpreted by the brain as sounds. Normally, sound waves in air enter the ear, and vibrate the ear-drum. These vibrations are transmitted to the nerve-endings by tiny bones acting as levers.

Loudness is determined by the strength, or amplitude, of the vibrations. It is measured in decibels.

Notes of the Scale The human mind is very expert at judging the relationship between a series of notes, and even a slight mistake in pitch for one of them is very displeasing. The relationships which are pleasing are arranged in a scale:

doh, ray, me, fah, soh, lah, te, doh.

When the frequencies are compared, the following are the ratios:

The Diatonic Scale

doh ray me fah soh lah te doh

$$1 \quad \frac{9}{8} \quad \frac{5}{4} \quad \frac{4}{3} \quad \frac{3}{2} \quad \frac{5}{3} \quad \frac{15}{8} \quad 2$$

e.g. if Doh has a pitch of 240, the notes which sound correct for a scale have frequencies as follows:

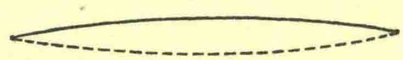
doh	ray	me	fah	soh	lah	te	doh
240	270	300	320	360	400	450	480

cycles per second

Overtones of Organ Pipes Open organ pipes emit all possible overtones, closed organ pipes emit only half as many; so a closed pipe and an open pipe, sounding the same note, have a very different quality.

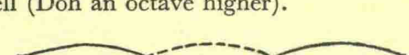
Overtones in Stringed Instruments Stringed instruments do not usually produce a single pure note, but a combination of harmonics, as shown in the diagrams below:

String at rest

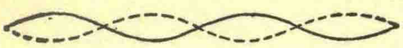


String set into vibration to sound its fundamental note n (Doh).

String also vibrates like this. Half the wavelength, double the frequency. Note of 2n as well (Doh an octave higher).



Also like this. $\frac{1}{3}$ the wavelength ∴ note of 3n as well (Soh in upper octave).



Also like this. $\frac{1}{4}$ wavelength ∴ note of 4n as well (Doh another octave higher). And so on. The design of a stringed instrument determines the strength of each of the various overtones (or harmonics) and so determines the "quality" of the sound produced. Similar harmonics are produced in wind instruments.

Phon The phon is a unit of loudness, as judged by the human ear. If a note (of any frequency) is judged by ear to be just as loud as one of 1,000 c.p.s. requiring x decibels of energy above zero intensity to produce it, the loudness of the note (or voice) is x phons. Some examples (approximations):

0 phons—sound just too faint to be heard.
20 phons—a whisper.
30 phons—a watch 3 ft. away.
60 phons—ordinary conversation.
100 phons—pneumatic drill.
110 phons—"running up" an aero engine.
130 phons—sound so loud that it begins to hurt the ear.

Pitch of a Note is determined by the frequency of vibration, i.e. the number of complete vibrations per second.

Quality of a Note Exactly the same note sung, in tune, by different people, and played on piano, flute, violin or other musical instrument sounds quite different. In every case, not only is the note itself (the fundamental) being produced, but a whole series of other (higher) notes (the overtones or harmonics). These vary from voice to voice and from instrument to instrument, thus giving "quality". The result is musical, because the harmonics are related by simple whole-number ratios to the fundamental.

This is not so in drums and other percussion instruments, where the harmonics (overtones) are produced as part of a circle, not as divisions of a length as in a string or a pipe, so the frequency relationship of the notes of a drum is not simple and the result is a noise, not a musical sound, though it can be tuned to the same fundamental frequency as a musical note.

Speed of Sound in Air This increases a little with rise in temperature. It does not depend on air pressure.

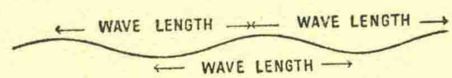
At 0°C.: 1,085 ft. per sec. or 740 m.p.h. or 331 m. per sec.
At 18°C.: 1,120 ft. per sec. or 765 m.p.h. or 342 m. per sec.

The speed of sound in air at normal temperatures is approximately 1 mile in 5 seconds. The speeds through other materials are as follows:

Substance	*ft. per sec.*	*m.p.h.*	*metres per sec.*
Fresh water	4,620	3,150	1,410
Sea water	5,050	3,450	1,540
Iron	16,400	11,200	5,000
Wood (average)	13,000	8,900	4,000

Ultrasonic Vibrations These are vibrations fast enough to be above the upper limit of audibility. Much use is being made of them, for example, in echo sounding. The pitch of a note is expressed by the number of vibrations (or cycles) per second.

Wavelength and Frequency If, at the seaside, we could measure the distance between the crest of one wave and the next, we would have the "wave-length" λ (pronounced "lambda").



If we count the number of waves passing a point in unit time, e.g. 1 minute, we have the "frequency" (n).

Since n crests, each λ apart, pass in unit time, the velocity (v) of the wave is nλ.

$$v = n\lambda.$$

Example: The crests of a wave are 30 ft. apart, and pass a point at the rate of 5 a minute. What is the velocity of the wave-motion?

$$v = n\lambda$$
$$\therefore v = 5 \times 30 \text{ ft. per minute}$$
$$= 150 \text{ ft. per min.}$$

Although the waves in air are "to and fro" (longitudinal), rather than "up and down" (transverse), the same law holds good.

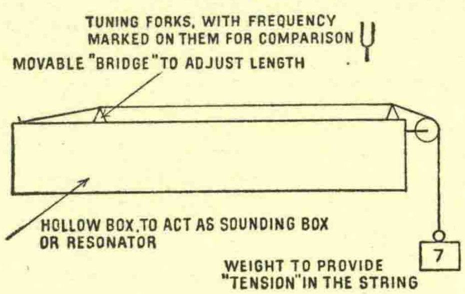
A COMPARISON BETWEEN THE SCALES

$$\text{Ratio} = \frac{\text{frequency of note}}{\text{frequency of Doh}}$$

Scale	Doh	Ray	Me	Fah	Soh	Lah	Te	Doh
Diatonic (ratio)	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Diatonic (decimals)	1·000	1·125	1·250	1·333	1·500	1·667	1·875	2·000
Equi-tempered	1·000	1·122	1·260	1·335	1·498	1·682	1·888	2·000

Some Experiments with Stringed Instruments

The sonometer, a single-stringed instrument used in a physics laboratory. The string is plucked or bowed at its centre. Various experiments may be carried out on it, and the results are described below.



A Sonometer.

1. *Effect of Length* (tension being unchanged). Bridge is moved.

Change in length	Effect on note	Change in frequency
Doubled (x 2)	Octave lower	x $\frac{1}{2}$
Halved (x $\frac{1}{2}$)	Octave higher	x 2
Made two-thirds $\left(x \frac{2}{3}\right)$	Doh→Soh	x $\frac{3}{2}$

The frequency of a vibrating string is inversely proportional to its length, i.e.

$$n \propto \frac{1}{l}$$

2. *Effect of Tension* (length being unchanged). Weights are changed.

Change in tension	Effect on note	Change in frequency	N.B.
Four times (x 4)	Octave higher	x 2	$2 = \sqrt{4}$
Nine times (x 9)	Soh of octave higher	x 3	$3 = \sqrt{9}$
A quarter (x $\frac{1}{4}$)	Octave lower	x $\frac{1}{2}$	$\frac{1}{2} = \sqrt{\frac{1}{4}}$

The frequency of a vibrating string is directly proportional to the square root of the tension, i.e.

$$n \propto \sqrt{T}$$

3. *Effect of Mass* (per unit length) of the string. Length and tension being unchanged.

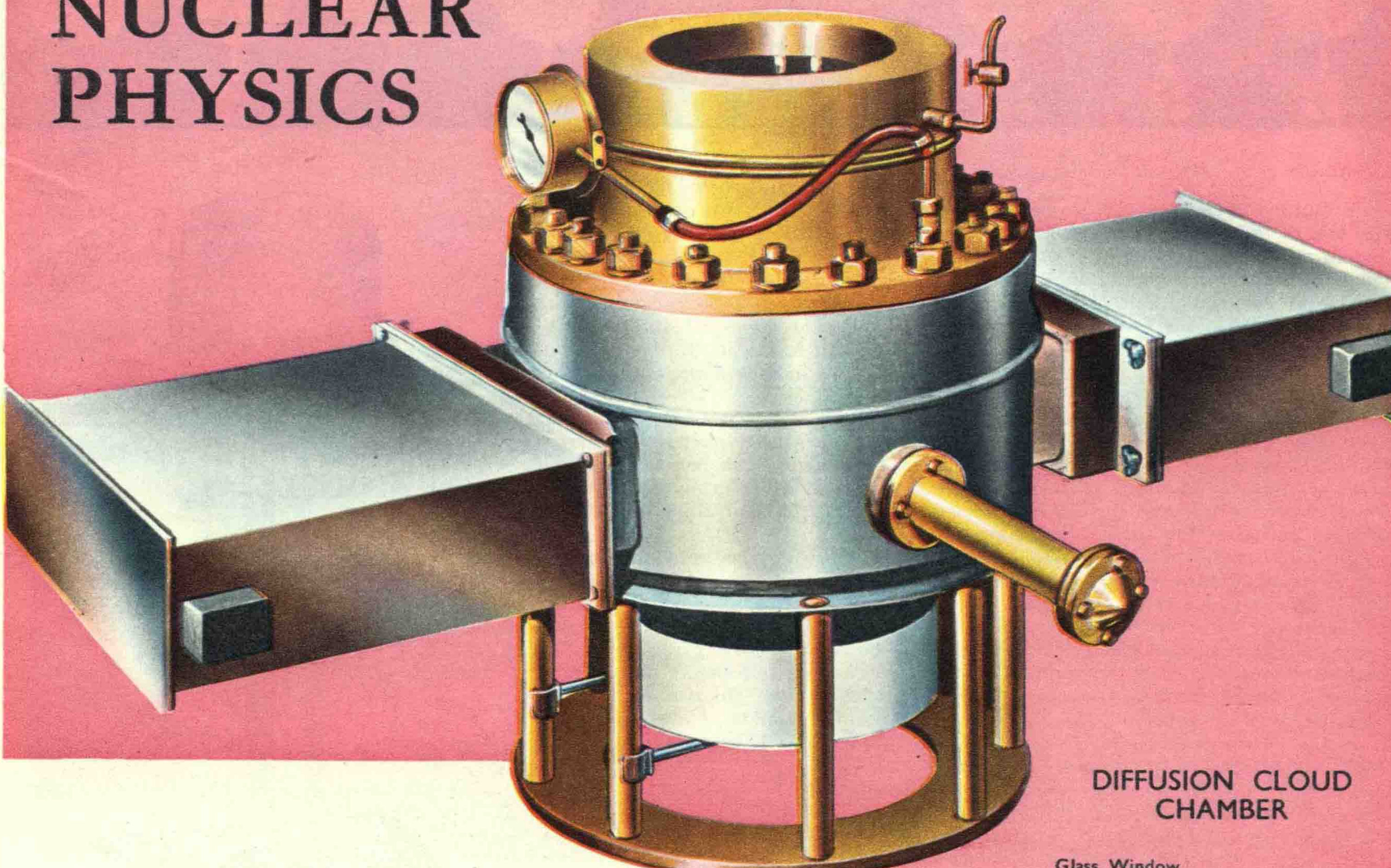
Thinner and thicker strings are fitted, the same length and tension being used.

Mass of string	Effect on note	Change in frequency	N.B.
Four times (x 4)	Octave lower	x $\frac{1}{2}$	$\frac{1}{2} = \frac{1}{\sqrt{4}}$
Nine times (x 9)	Doh→ Fah 2 octaves lower	x $\frac{1}{3}$	$\frac{1}{3} = \frac{1}{\sqrt{9}}$
A quarter (x $\frac{1}{4}$)	Octave higher	x 2	$2 = \frac{1}{\sqrt{\frac{1}{4}}}$

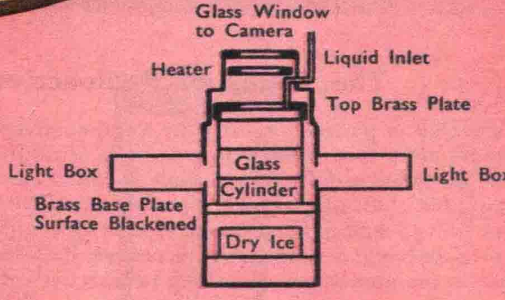
The frequency of a vibrating string is inversely proportional to the square root of its mass per unit length, i.e.

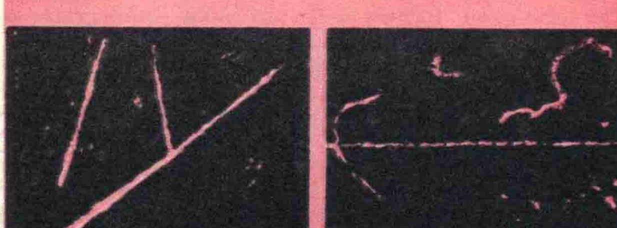
$$n \propto \frac{1}{\sqrt{m}}$$

NUCLEAR PHYSICS



DIFFUSION CLOUD CHAMBER





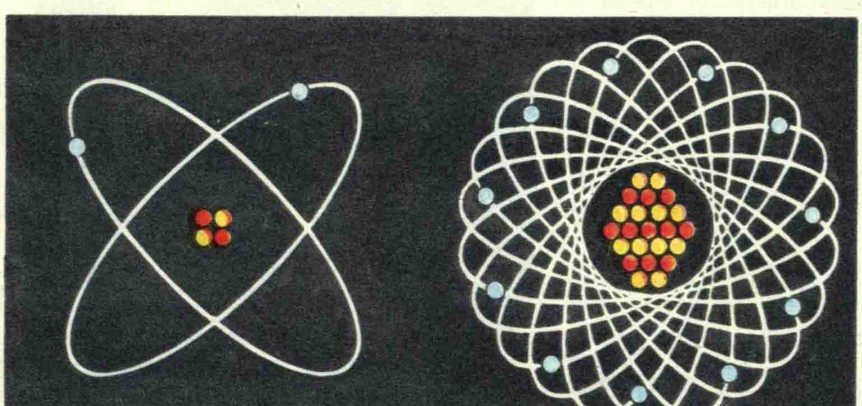
Nuclear Physics is concerned with the study of the nuclei of atoms. The nucleus is the extremely small core of an atom ; it is surrounded by the electrons that are usually regarded as moving around the nucleus in orbits just as the planets do around the sun. The number and arrangement of the electrons are responsible for the chemical properties of the atom (see The Science of Chemistry, page 186).

Virtually all of the weight of the atom is concentrated in the nucleus, which is built up from two types of particle with weights that are almost equal and about 1840 times greater than the weight of the electron. These two particles are the *proton*, which has a single unit of positive electric charge, and the *neutron*, which has no charge.

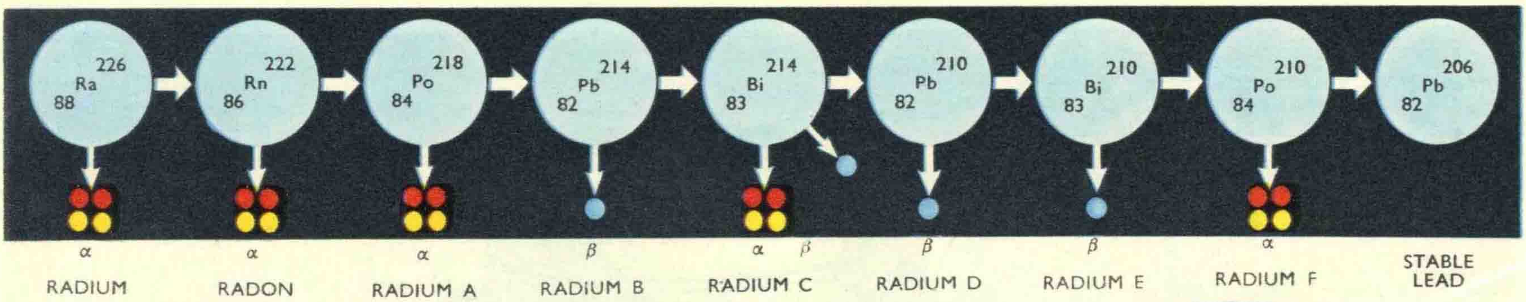
As the number of electrons surrounding the nucleus is equal to the number of protons in the nucleus, the atom as a whole is electrically neutral (the plus-charges balance the negative-charges). The number of protons (or electrons) is called the atomic number of the atom ; for short this is known by the symbol Z. All the atoms of a particular element have the same value of Z but the number of neutrons in the nucleus can vary slightly and so give rise to the existence of *isotopes*.

There are, for example, two isotopes in the gas chlorine, both have 17 protons in their nuclei, that is $Z = 17$, but one has 18 neutrons and the other has 20. These two isotopes therefore have weights that are almost exactly 35 and 37 times the weight of a single proton or neutron and for this reason their *mass numbers* are said to be 35 and 37 respectively. (Mass can be regarded as meaning the same as weight in much of what follows.)

Some atoms are described as *radioactive* because their nuclei undergo sudden changes. During these changes they emit particles or γ gamma rays or both. The sudden change is called the *disintegration* of the nucleus. The particles emitted are usually α (alpha) particles or β (beta) particles. The alpha α particle is commonly emitted by the heaviest nuclei and consists of two protons and two neutrons in close association ; it is, in fact, identical with the nucleus



HELIUM SODIUM



of the isotope of helium with a mass number of 4, and carries two units of charge. The loss of an alpha α particle from a nucleus results in the formation of a new nucleus with a value of Z two units lower and a mass number four units lower. The beta β particle is simply an electron : the emission of an electron may at first sight seem impossible since there are normally no electrons in a nucleus. The explanation lies in the fact that the neutron can be regarded as a combination of a proton and an electron and so the loss of a beta β particle is accompanied by an increase of one in the number of protons in the nucleus and the disappearance of a neutron.

Quite often a disintegrating nucleus also emits a gamma γ ray, an event that involves no change in the weight or charge associated with the nucleus. Whereas α and β particles are readily stopped by matter, some γ rays can penetrate several inches of steel. Gamma γ rays are frequently regarded as electromagnetic waves of very short wave-length but on some occasions their behaviour resembles that of particles and they are then called *γ photons*.

A charged particle moving in a magnetic field follows a curved path and so it is possible to distinguish readily between the particles and γ rays. Electrons being negatively charged and very light are markedly deflected in one direction whereas α particles are deflected to a much lesser extent in the opposite direction. γ rays are not affected by a magnetic field.

Nuclear scientists need to distinguish between the various isotopes of an element. To the normal symbol Cl used in chemistry for the element chlorine they add a subscript (small number below) for the atomic number, and a superscript (small number above) for the mass number. So the isotope of Chlorine that has Z=19 and mass number of 35 becomes $_{19}Cl^{35}$

The alpha α particle has the symbol $_{2}He^{4}$

The Neutron has the symbol $_{0}n^{1}$

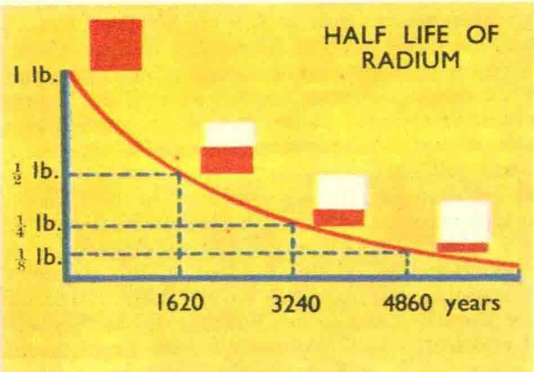
The beta β particle is usually written β^{-} which indicates its negative charge.

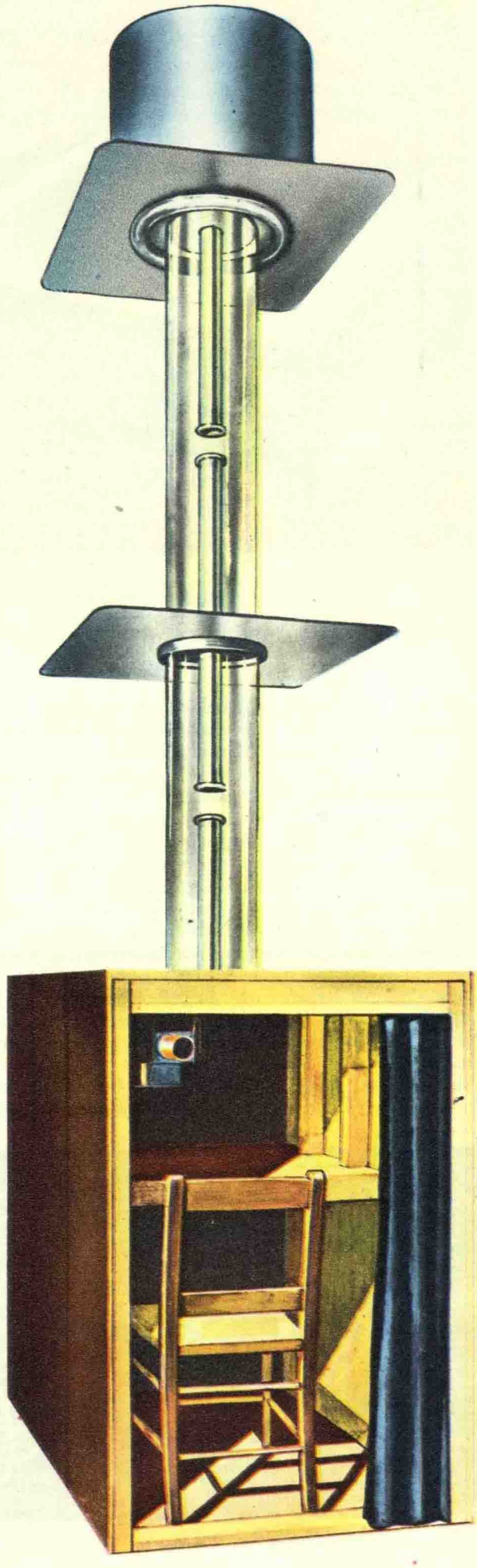
The Decay of Radioactive Substances

If the number of particles emitted by a radioactive substance in a minute is recorded it is found that this number decreases as time passes. The period during which the rate of emission falls by one half is called the *half-life* of the substance, and it is remarkable that, after another period equal to the half-life, the rate of emission is again halved and is then equal to only one quarter of the original rate. This process of halving during each successive half-life continues indefinitely and the decrease in the number of atoms of a radioactive substance with time is referred to as *decay*.

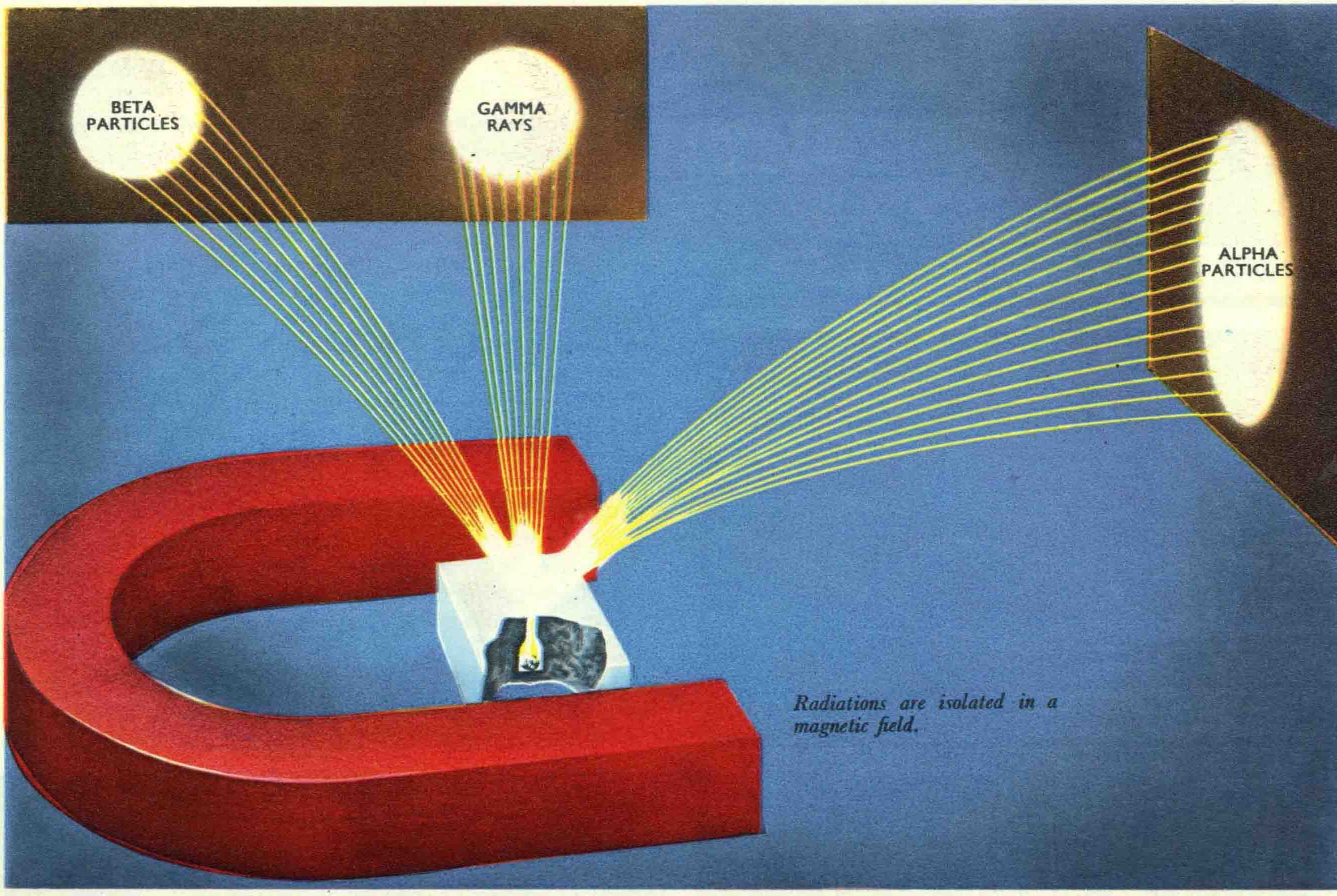
The new atom formed when an atom disintegrates is called a *daughter* and the original atom is referred to as the *parent*. It sometimes happens that the daughter is radioactive and that this in turn disintegrates to give radioactive products ; in this way a whole *series* or *chain* of radioactive substances may be formed. An example of this is provided by the $_{88}Ra^{226}$ isotope from which derive many radioactive products by the emission of either α or β particles before a daughter that is not radioactive is produced ; this final product is an isotope of lead, $_{82}Pb^{206}$.

A knowledge of the value of the half-life of an unknown isotope can frequently assist in its identification, and as the value is dependent upon only the nuclear properties of the atom (not upon the electrons on which chemical differences depend) the half-life will be the same for any chemical compound in which the isotope may be incorporated. So the isotope can be traced through complicated chemical changes.





The original atom-splitting machine which, in 1932, brought about the first artificial splitting of an atomic nucleus. It was designed by the scientists Cockcroft and Walton (see Famous Scientists).



Radiations are isolated in a magnetic field.

Detection of Particles and Gamma Rays

To measure the number of particles or rays being given off by a radioactive substance a *detector* apparatus is used. It will respond to the radiation and provide an electrical output; the use of electronic amplifiers then enables the sensitivity of the device to be increased, if necessary, to the point where individual particles can be detected.

The operation of many detectors depends upon the fact that a fast-moving charged particle can dislodge electrons from the atoms of gas through which it moves; the particle therefore leaves a trail of *ion-pairs*, each of which consists of a dislodged electron and the now positively charged atom, or as it is usually called, *ion*. If the ion-pairs are produced between a pair of parallel metal plates that are connected to the terminals of a battery, the positively charged ions will be attracted to the negative plate and the electrons will move towards the positive plate; such a movement of charges results in a current being drawn from the battery. By passing this current through a resistor it is possible to produce a voltage pulse that can be amplified electronically and be made to operate a register to record the number of particles. A simple device like this can be used to count alpha α particles because they produce a very large number of ion-pairs in just a few inches of travel.

Beta β particles can produce far fewer ion-pairs between the plates and individual particles are not readily detected by this apparatus; but they can be detected by using a different form of the detector consisting of a hollow cylinder along the axis of which is placed a thin wire connected to the positive terminal of the battery, while the cylinder is connected to the negative terminal. When particles enter the cylinder they produce ion-pairs as before but as the electrons move towards the wire they are now accelerated to a speed that makes them dislodge electrons from further atoms; thus one particle may result in there being produced in the external circuit a current that is equivalent to *many* beta β particles, and this magnified current can easily be measured. It is a remarkable thing that if the voltage between the wire and the cylinder is increased, a point is reached where the entry of a *single* particle into the cylinder results in the production of a very large number of free electrons and ions along the whole length of the wire and a very large electrical output is obtained — this kind of detector is called a *Geiger-Mueller Counter*.

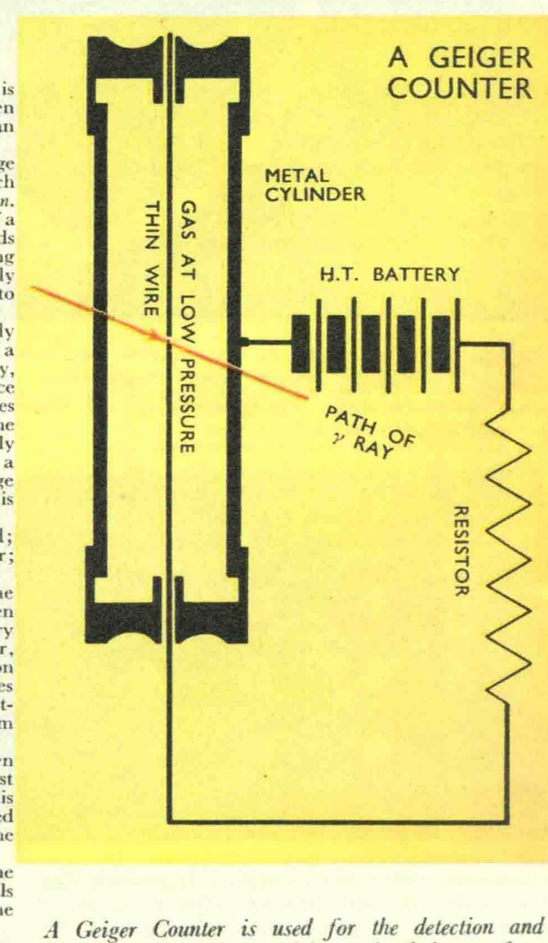
It is normal to use a special mixture of gases in the counters just described and so they are usually sealed; it is then necessary to provide a window made of very thin metal or mica through which particles may enter; it may even be arranged that the radioactive material can be placed inside the counter.

The first apparatus used to detect individual α particles was basically a thin layer or screen of very fine zinc sulphide crystals that was viewed through a microscope. A small flash of light or scintillation was seen when an alpha α particle struck one of the atoms in the screen. Nowadays this scintillation counter is a very important type of detector for it is now possible to use a special kind of photocell, known as a photomultiplier, to 'look at' the screen and to provide an electrical output whenever there is a flash of light. Scintillation counters are now commonly used to detect beta β particles and gamma γ rays in addition to alpha α particles and for such purposes various other materials that scintillate when irradiated are used, of particular importance are anthracene for the detection of beta β particles and sodium iodide containing a little thallium iodide for gamma γ rays.

An important type of detector that does not provide an electrical output is the *cloud chamber*; it has been used in the study of the reactions that occur between nuclei and particles and it was used in some of the first experiments that showed that atoms could be 'smashed'. The device consists of a chamber in which there is air saturated with water vapour. In use the air is made to expand suddenly and the passage of a charged particle then results in the formation of droplets along its path, a sort of 'vapour trail'. Photographs of the tracks are usually taken from two directions so that a three dimensional record may be obtained.

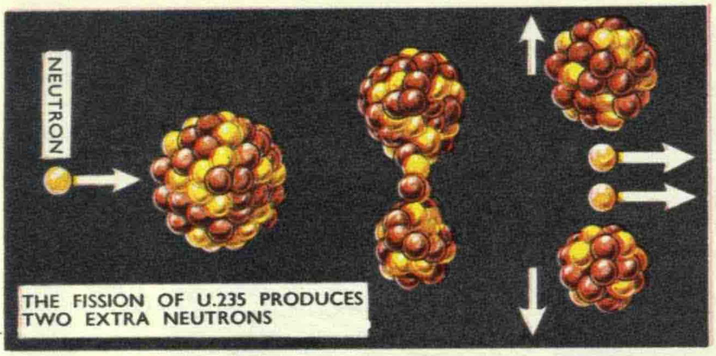
Gamma γ rays and particles from a radioactive substance cause darkening of a photographic plate and one of the chief uses of this effect is in personnel monitoring. Each person working with radioactive materials wears a small piece of photographic film for a period of about a week; the film is then developed and the amount of radiation received by the individual is assessed from the blackening.

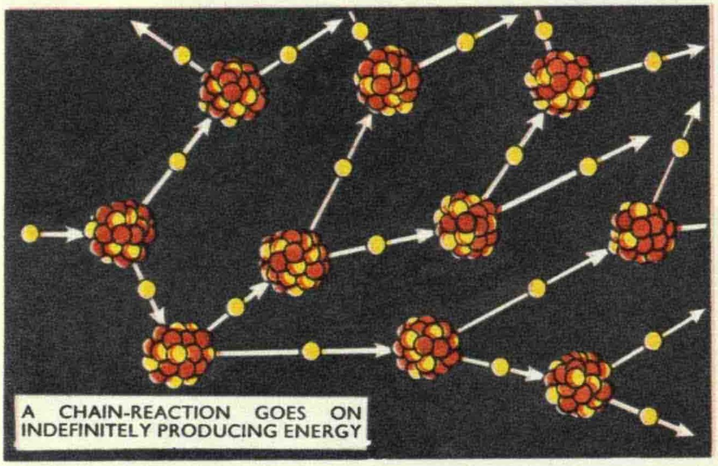
Neutrons, being uncharged, do not directly affect any of the devices considered so far but they can be detected by counters containing a material such as boron trifluoride with which neutrons interact with the production of alpha α particles for these are then readily detected.



A Geiger Counter is used for the detection and measurement of the particles emitted by or from radioactive substances.

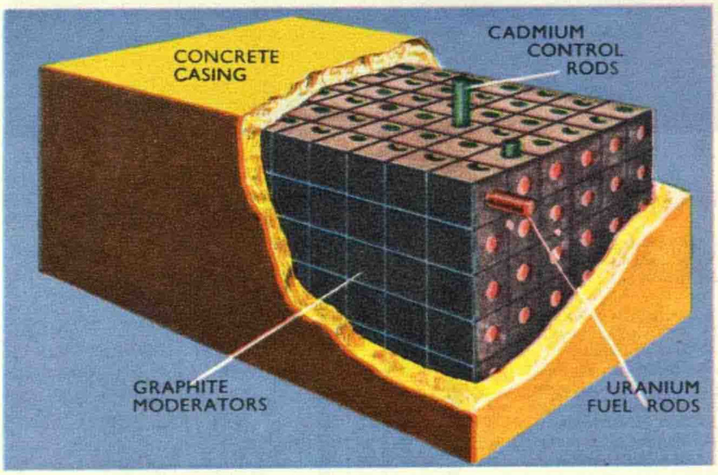
Fission and Atomic Reactors



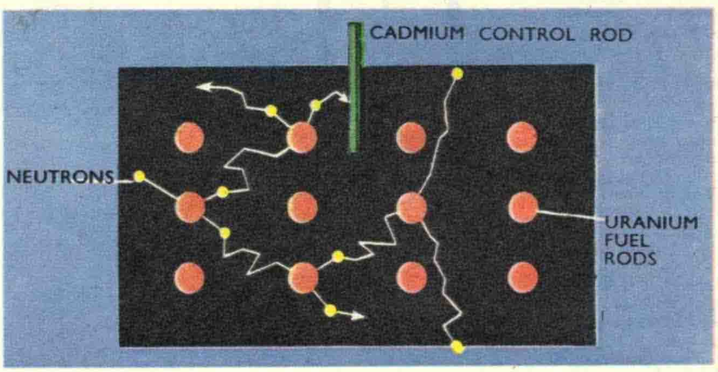


The result of bombarding uranium with neutrons is remarkable because the isotope ${}_{92}U^{235}$, besides capturing slow neutrons and thereby producing ${}_{92}U^{236}$, sometimes splits into two parts, one of which usually has a weight about one and a half times that of the other. Two highly important points about this splitting or *fission* are the release of an enormous quantity of energy, and the fact that either two or three neutrons are also produced. The possibility therefore exists of using these neutrons to bring about fission in further ${}_{92}U^{235}$ atoms and of starting a *chain reaction* in which such a process would be repeated indefinitely ; the neutrons to start such a reaction would normally be available on account of alpha particle-neutron reactions in surrounding materials or from the small number of spontaneous fissions that occur in uranium.

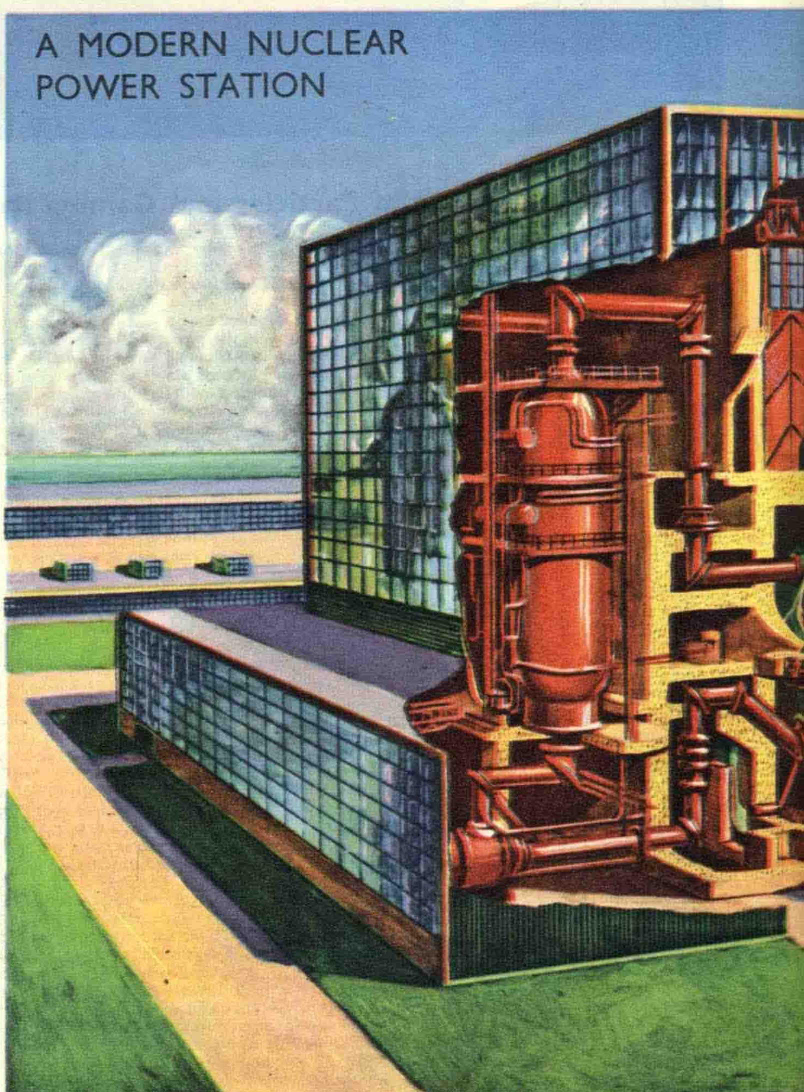
There are, however, great practical difficulties in the way of producing a chain-reaction in natural uranium ; one of these arises from the fact that for every atom of fissile ${}_{92}U^{235}$ in uranium there are about one hundred and forty ${}_{92}U^{238}$ atoms which, for the most part, capture neutrons without undergoing fission. It is just possible to establish a chain-reaction if some tons



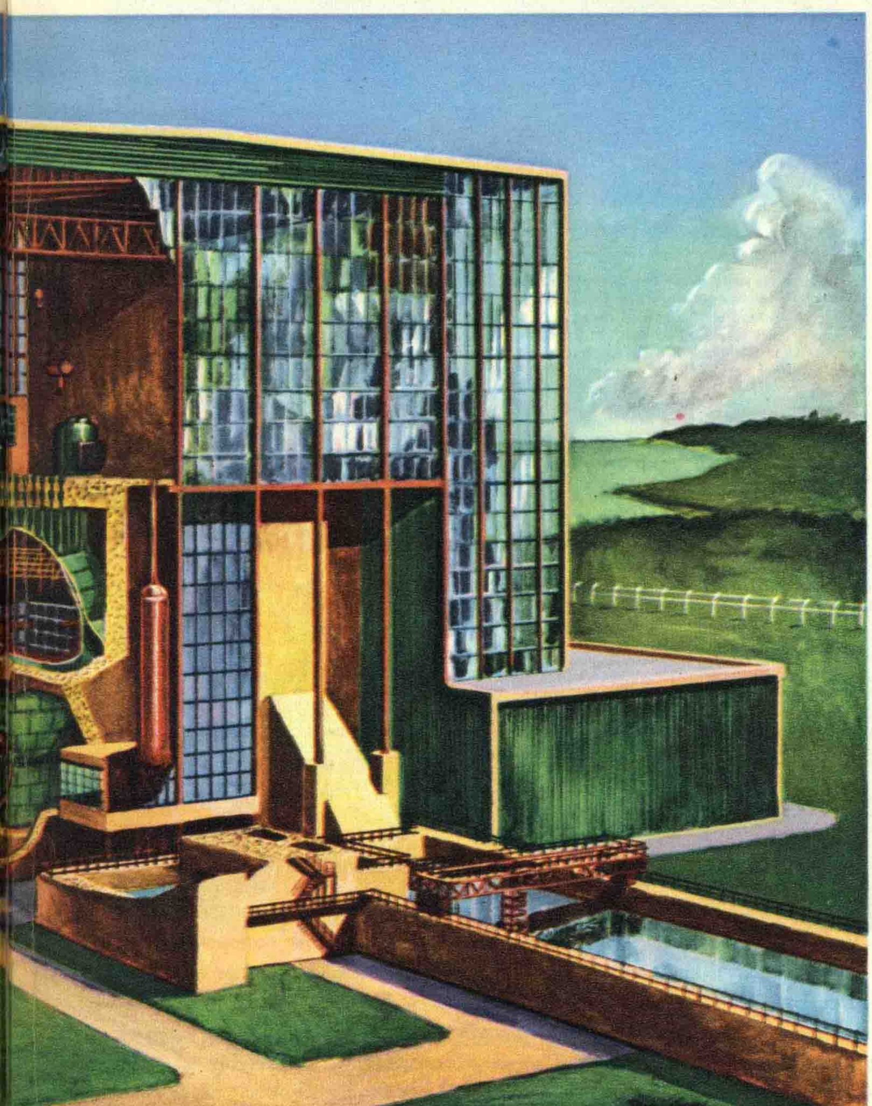
This type of nuclear reactor may be found in many modern nuclear power stations. The cutaway concrete casing is necessary to protect the workers from radiation hazards. The cadmium rods are automatically inserted if the reactor becomes too hot.



The diagram shows neutrons emitted by uranium 235. Some are captured by the cadmium control rod but others go on to cause fission in further uranium nuclei. A chain-reaction is maintained in this way. The graphite slows down the neutrons making them more efficient.



THE MUSHROOM CLOUD OF AN ATOM BOMB EXPLOSION



of uranium are distributed throughout a large mass of graphite which slows down the neutrons (acts as a moderator).

The use of a controlled chain-reaction for the production of power is achieved in a *reactor*. An important consideration in the operation of a reactor is that a fixed level of power output requires that one, and only one, neutron must become available for producing fission for every atom that undergoes fission ; if the number made available is less than one then the reaction will quickly die out, whereas if it is greater than one then the number of neutrons in the reactor will quickly increase, an enormous amount of heat will be released and the reactor will be destroyed ; no atomic explosion, however, could occur in such a reactor.

The easiest way of keeping a steady number of neutrons in a reactor is to arrange that the uranium and graphite together would sustain a chain-reaction and then to control the reaction by inserting *control rods*, which contain good absorbers of neutrons such as boron or cadmium. This keeps the number of neutrons at the desired level. The control rods are fully inserted when the reactor is to be shut down. The production of power in a reactor is due to the fact that the weight of the products of fission is slightly less than the weight of the original neutron and ${}_{92}U^{235}$ atom, and it is this small amount of matter that is converted into energy in accordance with Einstein's Theory. An extremely important feature of the reaction, as with many other reactions in which a neutron is captured, is that the product, here Co 60, is radioactive (it emits β particles and γ rays and has a half-life of 5.25 years). The disintegration of the Co 60 atom results in the production of an isotope of nickel :

$$ {}_{27}Co^{60} \quad = \quad {}_{28}Ni^{60} \quad + \quad \beta $$

The likelihood of the capture of a neutron by a nucleus is in general increased if the neutron is moving only slowly. Neutrons can be slowed down by passing them through a moderator, which is usually built up of light atoms with which the neutrons repeatedly collide ; commonly used moderators include graphite and "heavy water" ; it is naturally important that a moderator should absorb as few as possible of the neutrons.

The Atomic Bomb

A chain-reaction in natural uranium, with its very small (one in 140) content of the fissile isotope U 235, is possible only if a very large weight of uranium is used, and even then it is necessary to use a moderator to slow down the neutrons. With pure U 235 it is possible to use *fast*-moving neutrons to maintain a chain-reaction and so a moderator is not required. In a certain quantity of U 235 (known as the critical mass) a chain-reaction will start automatically owing to the presence of stray neutrons: only amounts less than the critical mass will be stable. Thus it is possible to bring about a nuclear explosion by arranging the sudden joining together of a super-critical mass, perhaps by projecting one sub-critical mass at another one so that the two together form a super-critical mass.

The absence of materials, such as U 238, that absorb neutrons without producing fission assists in the extremely rapid rise in the number of neutrons and fissions in an atomic bomb, the power of which may equal that of several tens of thousands tons of a conventional explosive like TNT.

The production of uranium that contains a high proportion of U 235, and known as *enriched uranium*, has been achieved on a large scale by several methods. In one the uranium is first converted into a volatile compound, uranium hexafluoride, and this in gaseous form is allowed to diffuse through a very large number of filters: the molecules containing the U 235 atoms diffuse more rapidly and so separation of the isotopes results.

A second method involves the use of an electromagnetic separator in which the uranium atoms are converted into ions that are made to travel in curved paths in a magnetic field; the U 235 ions travel in tighter curved paths than those of the U 238 ions and so the two isotopes can be collected separately.

Both of these separation methods are very expensive to operate and so considerable importance attaches to another fissile material—plutonium, or more precisely, one particular isotope, ${}_{94}Pu^{239}$. This isotope is produced in an atomic reactor containing U 238 by the following reactions.

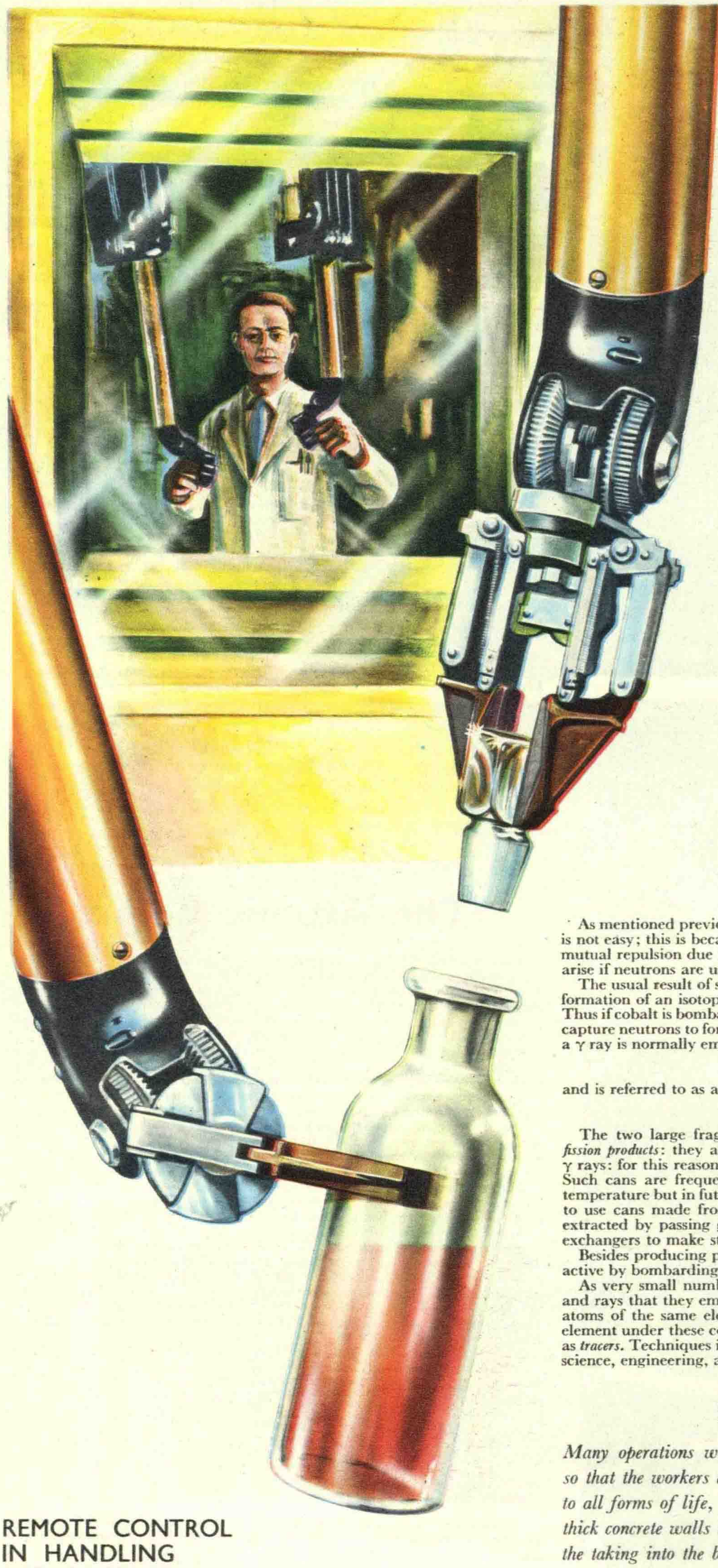
$$ {}_{92}U^{238} + {}_{c}n^{1} = {}^{29}U^{239} $$

$$ {}_{92}U^{239} = {}_{93}Np^{239} + \beta $$

$$ {}_{93}Np^{239} = {}_{94}Pu^{239} + \beta $$

(Np is the symbol for neptunium)

As the chemical properties of plutonium and uranium are different it is possible to separate them chemically. In addition to this advantage it is also possible to use U 238 for the production of atomic energy if it is first converted into plutonium. Some reactors in which enriched uranium is used as the fuel are designed to effect such a conversion in addition to producing power. It is even possible in a *breeder reactor* to produce more fissile material than is consumed.



REMOTE CONTROL IN HANDLING RADIOACTIVE ISOTOPES

Artificial Radioactivity

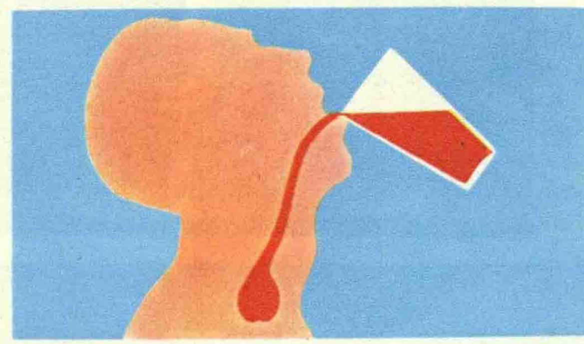
Radioactivity is not only confined to the heaviest atoms. The nuclei of the lighter atoms, can be changed by bombarding them with suitable projectiles. Some of the earliest examples of such 'atom smashing' involved the use of particles from a naturally occurring radioactive element to bombard light atoms. Although a very large number of α particles was used only a very few interacted with nuclei but when the nucleus of an atom of nitrogen was struck it was found that a proton was immediately emitted from the nucleus and that an atom of oxygen remained: thus nitrogen was *transmuted* into oxygen. The reaction may be written as an equation:

$_7N^{14}$	+	$_2He^4$	=	$_8O^{17}$	+	$_1H^1$
Nitrogen		α particle		Oxygen		Proton
Z = 7		Z = 2		Z = 8		Z = 1
Weight = 14		Weight = 4		Weight = 17		Weight = 1

It will be seen that the sum of the values of Z for oxygen and the proton is 9 and is equal to the sum of the values for nitrogen and the α particle; a similar rule governs the weights of the particles and atoms.

Another reaction between α particles and light atoms is the one in which a neutron is emitted instead of a proton; an important example is provided by a mixture of beryllium (a light element) and radium (which with its daughter products emits α particles), the reaction is:

$_4Be^9$	+	$_2He^4$	=	$_6C^{12}$	+	$_0n^1$
Beryllium		Particle		Carbon		Neutron



Radioactive iodine is used to study disorders of the thyroid gland. The iodine collects in the gland and the amount absorbed will indicate the extent of any disorder. An abnormal thyroid would absorb either too much or too little.

As mentioned previously the penetration of the positively charged nucleus by an α particle is not easy; this is because of the small sizes of the target and projectile and because of their mutual repulsion due to both of them having positive charges. The latter difficulty does not arise if neutrons are used as projectiles since they, having no charge, are not repulsed.

The usual result of striking a nucleus with a neutron is the capture of the neutron and the formation of an isotope with a weight that is one unit higher; the value of Z is unchanged. Thus if cobalt is bombarded with neutrons, the nuclei of the atoms, which have a weight of 59, capture neutrons to form atoms that have a weight of 60, and although no particles are ejected a γ ray is normally emitted. The reaction is written as:

$$_{27}Co^{59} + {}_0n^1 = {}_{27}Co^{60} + \gamma$$

and is referred to as a neutron-gamma reaction: the equation may be abbreviated to:

$$_{27}Co^{59}\ (n,\gamma)\ {}_{27}Co^{60}$$

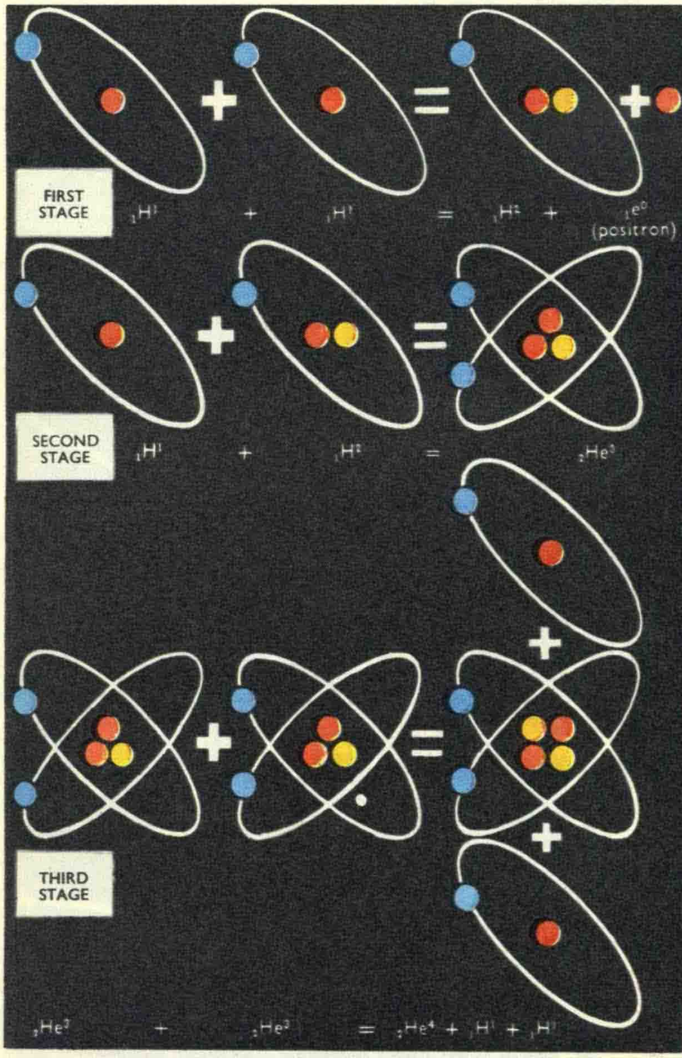
The two large fragments left over after the fission of the uranium nucleus are called *fission products*: they are, for the most part, intensely radioactive and emit β particles and γ rays: for this reason and others the fuel rods of uranium in a reactor are encased in cans. Such cans are frequently made of aluminium when the reactor operates at a moderate temperature but in future, when much higher temperatures are envisaged, it will be necessary to use cans made from stainless steel or beryllium. The power developed in a reactor is extracted by passing gas through the reactor, and the heated gas is then used in the heat exchangers to make steam to drive turbines and generators to produce electricity.

Besides producing power a reactor is frequently used as a source of materials made radioactive by bombarding them with neutrons.

As very small numbers of radioactive atoms can be detected on account of the particles and rays that they emit it is possible to mix them with a large number of ordinary inactive atoms of the same element and then to follow the course taken by all of the atoms; the element under these conditions is said to be *labelled* and the radioactive atoms are referred to as *tracers*. Techniques in which tracers are used have been of great value to many branches of science, engineering, and medicine.

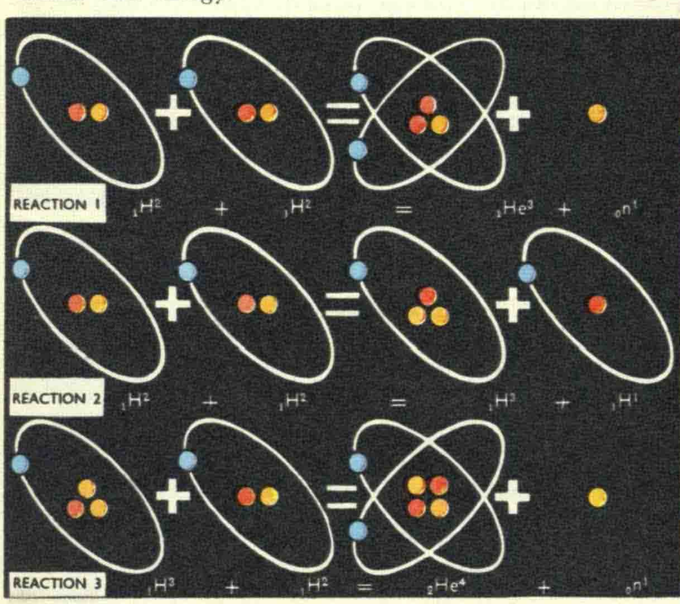
Precautions against Radiation

Many operations with radioactive materials are performed remotely by instruments so that the workers are not exposed to the harmful radiations, for radiation is deadly to all forms of life, and reactors have to be radiation-insulated with lead shields and thick concrete walls that the rays and particles cannot penetrate. A further hazard is the taking into the body of radioactive materials and this is minimised by scrupulous attention to the decontamination of working areas and by the wearing of special clothing. Radiation is all the more dangerous because its effects are, at first, invisible.



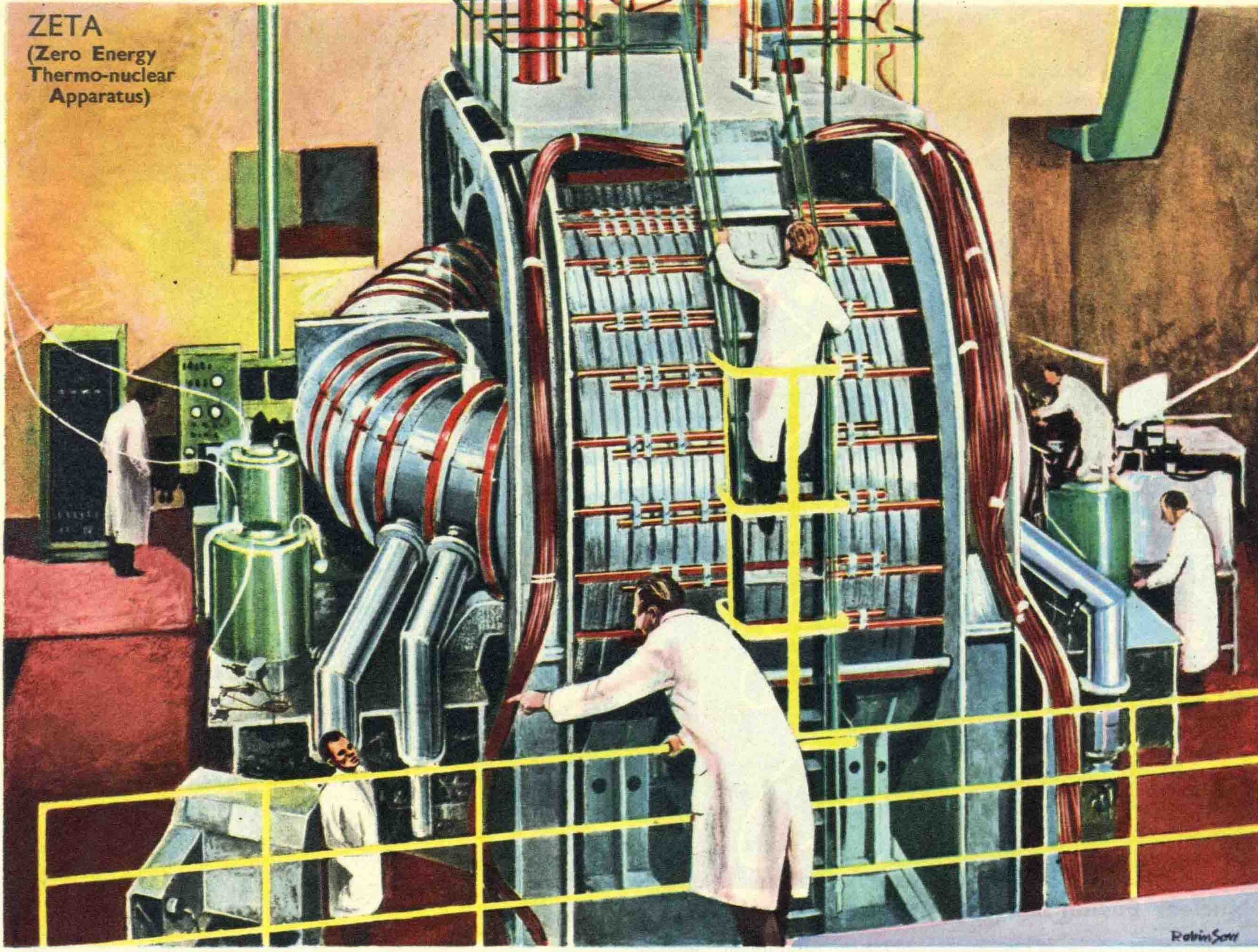
Nuclear Fusion and the Hydrogen Bomb

The controlled release of nuclear energy for the production of useful power has so far relied on the fission of the heavy atoms of U 235. The process involves the conversion of matter into energy.



It is possible to achieve a similar conversion of matter into energy by the *fusion* of the nuclei of light atoms because as in nuclear fission the weight of the products is less than that of the combining nuclei. Like that of all the stars the heat of the sun is produced as a result of nuclear *fusion* processes. At the present time the only practical man-made demonstrations of fusion, or " thermo-nuclear reactions " in which large amounts of energy have been released are the explosions of hydrogen bombs. In these a fission bomb has been used to trigger off the reaction, for immensely high temperatures and pressures are necessary before fusion of light elements can take place.

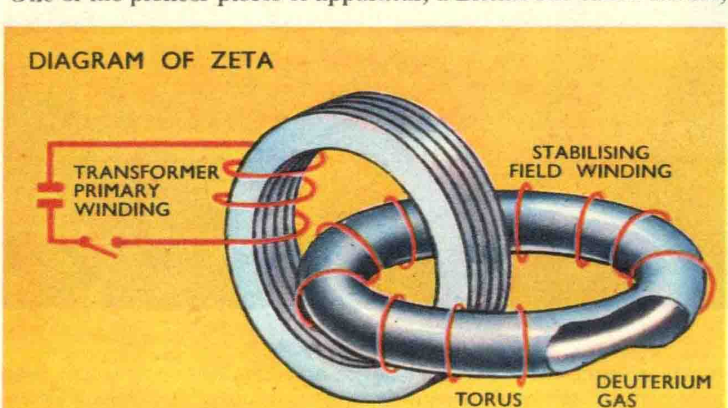
Much effort is being devoted in the U.K., U.S.A. and the U.S.S.R.



to the problem of releasing the energy of fusion in a controlled manner. The experiments commonly involve imparting a lot of energy to the gas deuterium, or heavy hydrogen, $_1H^2$, by heating it to a temperature of some millions of degrees so that the molecules acquire velocities sufficiently high for collisions to lead to the fusion of the nuclei.

At such temperatures, however, the gas not only exists as separate atoms but even the atoms have their electrons stripped off them, and so a mixture of electrons and ions, known as a *plasma*, is formed. An important aspect of this is that the gas becomes a conductor of electricity and so can be heated by passing an electric current through it. It can also be confined by magnetic fields to prevent it touching the walls of the vessel, and melting them. One of the pioneer pieces of apparatus, a British one called ZETA, was completed in 1958 and used in research into thermo-nuclear reactions at the Atomic Energy Research Establishment at Harwell. It consisted essentially of a torus, or endless tube, in which the gas was heated ; large electromagnets served to keep the discharge away from the walls.

A great difficulty, as with all the present machines, was that the plasma could be kept stationary for only a small fraction of a second and this did not prove long enough for the desired reaction to occur. Zeta was abandoned in 1960, but it seems probable that it is the forerunner of many developments in the search for man-tamed nuclear fusion to parallel the energy sources of the sun.

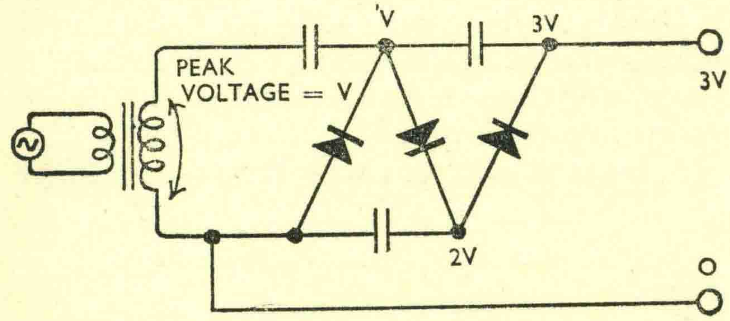


Heavy Water

A most important raw material in the field of atomic energy is heavy water. Physically it is very similar to ordinary water of which it forms part to the extent of 0.015%. It is used extensively as a moderator in fission reactors because it is composed of light atoms and has a very low affinity for neutrons. It may also well prove to be a starting material for the production of thermo-nuclear power. One method for separating it from water is to electrolyse a solution of water and potassium hydroxide. The hydrogen given off at the cathode contains a lower proportion of deuterium than the solution does with the result that the solution becomes enriched in deuterium. Vast amounts of electrical power are required in the process and so the separation has normally been carried out in those countries that can produce electricity cheaply from hydroelectric sources. This is why the Nazis put their atom bomb heavy-water plants in Norway during the last war.

Apparatus and Machines used in Nuclear Physics Experiments

Although nuclear physics is concerned with the smallest particles of matter, it has often been necessary to use enormous machines to determine their properties. In this section it is intended to give a few details of some of these machines.

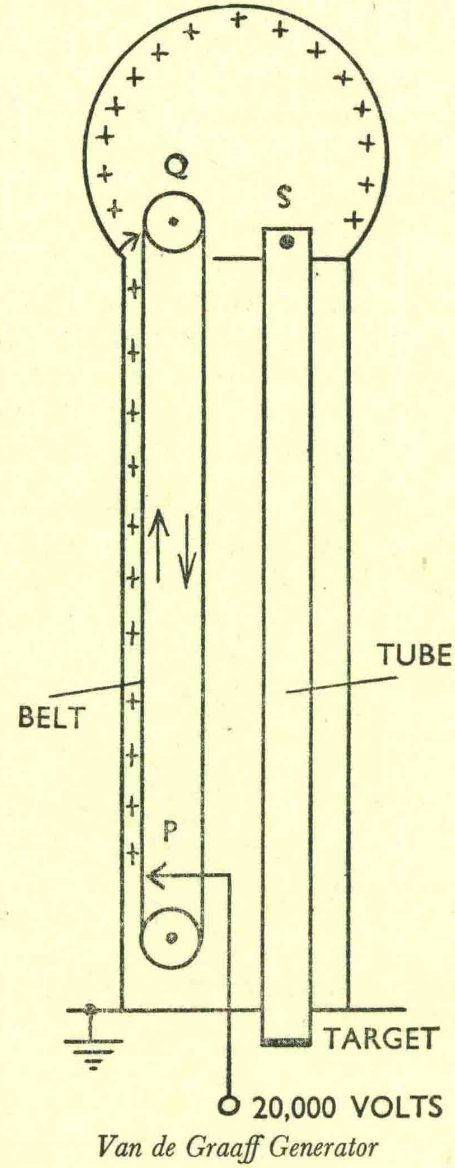


Accelerator

Of the utmost significance in the discovery of the behaviour of charged particles and atoms have been various accelerators; their use has freed workers from an earlier dependence on particles emitted by naturally occurring radioactive materials.

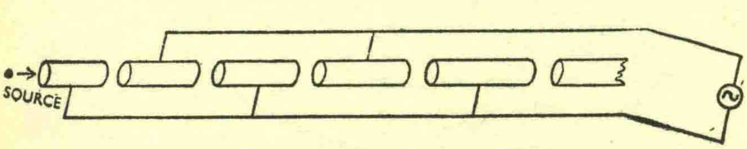
In the early machines the charged particles were accelerated through a powerful electric field produced from a relatively low potential (or voltage) by a combination of condensers and rectifiers (see diagram) or by an electrostatic generator. The high voltage is applied between the ends of an evacuated tube at one end of which is placed a source of the ions to be accelerated and at the other end the target.

One of the first electrostatic generators for use in the study of particles was designed by Van de Graaff; it consists essentially of a fast-moving non-conducting belt that is used to carry electric charge from a relatively low potential to a sphere which may reach a potential of up to ten million volts. Up to twenty thousand volts are applied to the point P (see diagram) and electrons are attracted from the belt so that it acquires a positive charge, which is then carried up to the spherical cap, where a set of points, S, supply electrons to the belt and leave the sphere with a positive charge. Because the sphere is hollow it can always accept (at Q) the charge brought to it by the belt, and the voltage of the cap will increase until the rate of leakage prevents any further rise.



Van de Graaff Generator

An alternative approach to the problem of producing high energy particles has been to impart a large number of small increments of energy to them and in this way finally obtain particles with very high speeds and energies without the use, at any stage, of the exceedingly high voltages used in the first two machines. The linear accelerator uses this principle. It consists of a series of hollow cylinders placed in line as shown in the diagram and it will be seen that alternate cylinders are connected together and to one terminal of a high frequency oscillator. The

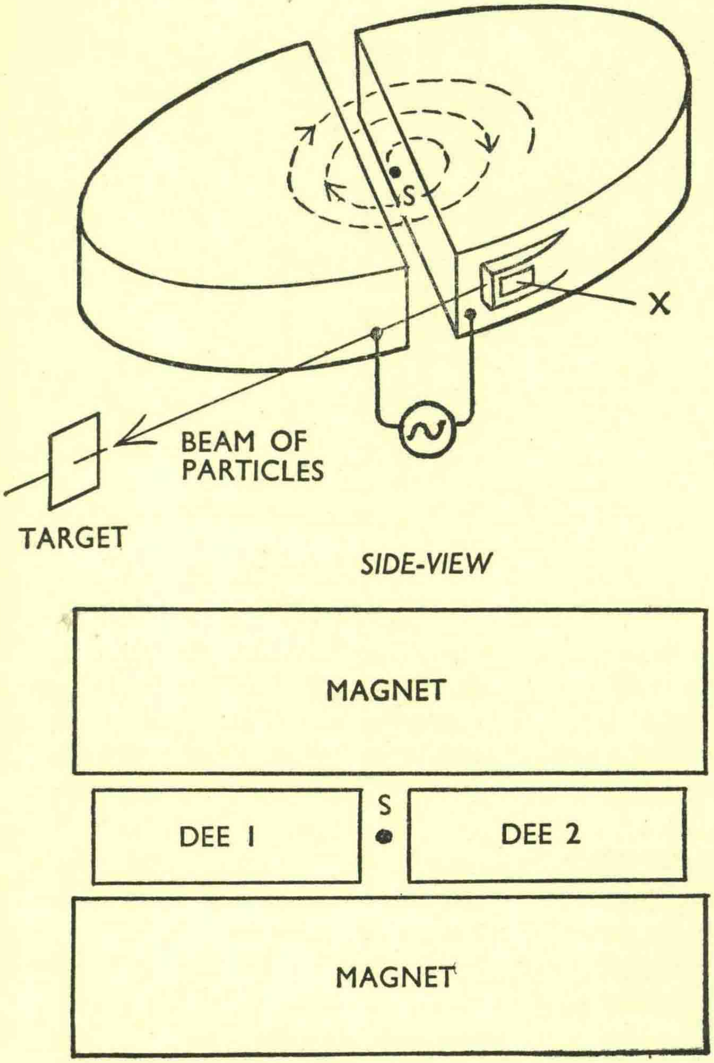


Linear Accelerator

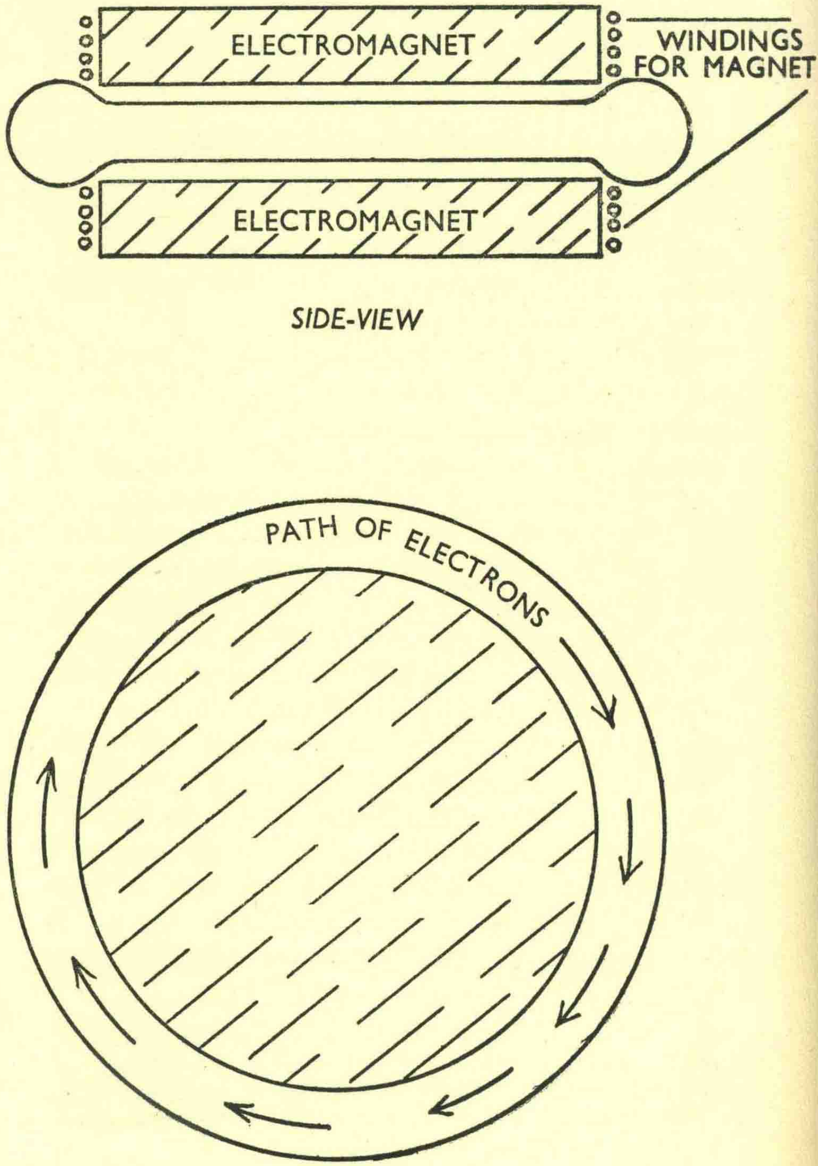
action involves the acceleration of particles across the gap between the first and second cylinders and their passage through the second cylinder at constant speed until they reach the next gap, by which time the potential on the cylinders has been reversed so that the particles are again accelerated; this process is continued along the length of the machine, which may have some tens of cylinders. By arranging that the lengths of the cylinders are gradually increased along the length of the apparatus the particles arrive at the gaps at the correct instants even though the frequency of the oscillator remains constant.

An obvious limitation of the linear accelerator is that the number of cylinders cannot be increased indefinitely. This difficulty was overcome in the cyclotron in which the particles are made to follow a spiral path in a pair of semi-circular boxes, connected to an oscillator, and referred to as "dees", on account of their shape. The particles are introduced at S and are accelerated across the gap between the dees, but as there is a magnetic field present they circle round and recross the gap many times. The path length of a particle in the dees is gradually increased by making it travel in a spiral, and so, although the speed increases, the particle remains precisely in step with the changes in polarity of the dees. When the particles have reached a path that is close to the perimeter of the apparatus they are deflected out of it by the charged plate at X and impinge on the target. The cyclotron in a form similar to that shown in the diagram is suitable for the acceleration of heavy ions such as protons, deuterons and α particles; it is not well suited to the acceleration of β particles or electrons.

High-speed electrons have been produced in



Cyclotron



Betatron

the Betatron in which the particles are constrained to move in a circular path by a magnetic field of gradually increasing intensity; the electrons are deflected from their circular path on to the target just as the field reaches its maximum intensity.

Reference has already been made to the cloud chamber as an instrument for determining the paths of the charged particles. In its original form it suffered from the fact that it took about five seconds to recover after use. This disadvantage has been avoided in the Diffusion Cloud Chamber, which is illustrated on page 81. The top of the apparatus is kept warm and has in it a trough containing a volatile liquid; vapour from this liquid, on leaving the trough, falls slowly through the apparatus and condenses in the cooled base. In the body of the apparatus there is maintained a region in which the conditions are just right for the formation of the droplets that will reveal the paths of particles.

TABLE OF THE ELEMENTS

Atomic No.	*Name*	*Mass numbers of isotypes*
1	Hydrogen	1, 2
2	Helium	3, 4
3	Lithium	6, 7
4	Beryllium	9
5	Boron	10, 11
6	Carbon	12, 13
7	Nitrogen	14, 15
8	Oxygen	16, 17, 18
9	Fluorine	19
10	Neon	20, 21, 22
11	Sodium	23
12	Magnesium	24, 25, 26
13	Aluminium	27
14	Silicon	28, 29, 30
15	Phosphorus	31
16	Sulphur	32, 33, 34, 36
17	Chlorine	36, 37
18	Argon	36, 38, 40
19	Potassium	39, 40°, 41
20	Calcium	40, 42, 43, 44, 46, 48
21	Scandium	45
22	Titanium	46, 47, 48, 49, 50
23	Vanadium	50, 51
24	Chromium	50, 52, 53, 54
25	Manganese	55
26	Iron	54, 56, 57, 58
27	Cobalt	59
28	Nickel	58, 60, 61, 62, 64
29	Copper	63, 65
30	Zinc	64, 66, 67, 68, 70
31	Gallium	69, 71
32	Germanium	70, 72, 73, 74, 76
33	Arsenic	75
34	Selenium	74, 76, 77, 78, 80, 82
35	Bromine	79, 81
36	Krypton	78, 80, 82, 83, 84, 86
37	Rubidium	85, 87°
38	Strontium	84, 86, 87, 88
39	Yttrium	89
40	Zirconium	90, 91, 92, 94, 96
41	Niobium	93
42	Molybdenum	92, 94, 95, 96 97, 98, 100
43	Technetium	
44	Ruthenium	96, 98, 99, 100, 101, 102, 104
45	Rhodium	103
46	Palladium	102, 104, 105, 106, 108, 110
47	Silver	107, 109
48	Cadmium	106, 108, 110, 111, 112, 113, 114, 116
49	Indium	113, 115°
50	Tin	112, 114, 115, 116, 117, 118, 119, 120, 122, 124
51	Antimony	121, 123
52	Tellurium	120, 122, 123, 124, 125, 126, 128, 130
53	Iodine	127
54	Xenon	124, 126, 128, 129, 130, 131, 132, 134, 136
55	Caesium	133
56	Barium	130, 132, 134, 135, 136, 137, 138
57	Lanthanum	138°
58	Cerium	136, 138, 140, 142
59	Praseodymium	140, 141
60	Neodymium	142, 143, 144°, 145, 146, 148, 150
61	Promethium	
62	Samarium	144, 147°, 148, 149, 150, 152, 154
63	Europium	151, 153
64	Gadolinium	152, 154, 155, 156, 157, 158, 160
65	Terbium	159
66	Dysprosium	156, 158, 160, 161, 162, 163, 164
67	Holmium	165
68	Erbium	162, 164, 166, 167, 168, 170
69	Thulium	169
70	Ytterbium	168, 170, 171, 172, 173, 174, 176
71	Lutetium	175, 176°
72	Hafnium	174, 176, 177, 178, 179, 180
73	Tantalum	180°, 181
74	Tungsten	180, 182, 183, 184, 186
75	Rhenium	185, 187°
76	Osmium	184, 186, 187, 188, 189, 190, 192
77	Iridium	191, 193
78	Platinum	190, 192, 194, 195, 196, 198
79	Gold	197
80	Mercury	196, 198, 199, 200, 201, 202, 204
81	Thallium	203, 205
82	Lead	204, 206, 207, 208
83	Bismuth	209
84	Polonium	
85	Astatine	
86	Radon	
87	Francium	
88	Radium	
89	Actinium	
90	Thorium	
91	Protactinium	
92	Uranium	
93	Neptunium	
94	Plutonium	
95	Americium	
96	Curium	
97	Berkelium	
98	Californium	
99	Einsteinium	
100	Fermium	
101	Mendelevium	
102	Nobelium	

The above table gives the Atomic Numbers of all the elements known at present, and the isotopes of the stable elements. Radioactive isotopes of otherwise stable elements are indicated by °.

The number of protons in an isotope is equal to the Atomic Number, the number of neutrons is equal to the difference between the Mass Number and the Atomic Number.

Types of Ray Encountered in the Study of Radio-active Behaviour

Alpha rays are made up of particles. They are bent by a magnetic field in such a way as to reveal a + ve charge on the particles. Weight and charge show that the particles are helium ions (i.e. the nuclei of helium atoms) with a + + ve charge.

They have great energy (being comparatively heavy for atomic particles) although rather slow moving (18,000 miles per sec.). This speed is about 100,000 times the velocity of gas molecules, but it varies somewhat according to the emitting source. It is because of this that rays are found to differ in range according to the means used to obtain them. Because of their larger mass they can penetrate the surrounding electron orbits of other atoms without suffering any deflection and *may* approach very close to the nucleus, when the α particle, due to repulsion by a like charge, will experience a sudden change of direction (deviation or deflection). They ionise a gas through which they pass. They are absorbed by 5/1,000 in. of aluminium or by a sheet of writing paper. They can penetrate through a gold foil 2,000 atoms thick. Their range in air is up to 8 cm. but it varies according to the source of the alpha particles.

Each particle falling on a zinc sulphide screen produces a scintillation.

Beta rays are made up of particles. These rays are bent by a magnetic field in such a way as to reveal a negative charge on the particles. In weight and charge they are alike to the particles of the cathode ray. They are electrons.

Electrons have very little weight, though as β rays they may travel at great speeds, varying from 62,000 to 180,000 miles per sec. (i.e. at their fastest they approach the speed of light). Fast electrons may have sufficient energy to penetrate the surrounding electron orbits of an atom. They are then deflected from their original course by the positive charge of the nucleus. They are more often turned through larger angles than is the case for α particles, since they have a much smaller mass. Slower electrons are more easily deflected, and in consequence more quickly lose their energy. Electrons ionise a gas through which they pass. They are able to penetrate ⅛ in. of aluminium or 2 mm. of lead.

When a narrow cathode ray beam is passed through thin metal foil the rays act like X rays (as if they were not particles but a radiation) and are diffracted giving an appropriate pattern on a fluorescent screen. They also show reflection off the face of a single nickel crystal. This means that beams of electrons can act as if they are made up of waves of definite wavelength as is the case for light (compare the electron microscope). Cathode rays are also found to cast shadows of objects in their path. This shows how difficult it is to distinguish usefully between particles and radiation—the latter itself measured as photons or quantum "packages"!

When (as a cathode ray) they are stopped by any solid object they set up X rays (an analogy would be machine-gun bullets striking a target and producing sound waves).

Each particle does not produce scintillation on a zinc sulphide screen, but the beam as a whole does produce scintillation.

When travelling slowly electrons are easily absorbed by atoms, even by those of gases.

X rays are electromagnetic radiations of various wavelengths intermediate between light rays and γ rays. They are not deflected by electric or magnetic fields.

Unlike light rays they have considerable penetrating power towards a metal screen. Hard X rays (of shorter wavelength generated by *very* high voltages and very low pressures in cathode ray tube) can penetrate up to 1 foot of solid steel. Softer rays penetrate less, and by suitable exposure can be used to make metal objects in the body (e.g. stomach) appear as dark shadows (i.e. as if opaque) on a screen. They show little trace of reflection at surfaces, and they are not refracted like ordinary light. They may be resolved into a spectrum by reflection from a crystal (more correctly, by diffraction due to the regular structure of the crystal).

X rays will fluoresce on a screen of platinum barium chloride.

Gamma rays are a form of radiation. They are not streams of particles. They are unaffected by a magnetic or electric field.

They are more penetrating than X rays, to which they are akin. They will pass through 1 ft. of iron or many inches of lead, and are only surpassed for penetrating by cosmic rays. They pass through much greater thicknesses of aluminium than β rays will do.

They ionise a gas through which they pass since they "knock out" (by energising them) some of the planetary electrons of the gas atoms; these electrons in their turn produce more ions from other atoms. Thus the cloud chamber tracks of gamma rays are very unlike those of ionising particles. They cause a diffuse, fluorescent screen to glow.

Cosmic rays. An extremely hard, penetrating radiation (i.e. of shorter wavelengths than γ rays) that can be detected by electroscopes and cloud chambers. These rays penetrate thick lead plates that would absorb gamma rays, though some parts of this very variable radiation may be absorbed by 10 cm. of lead. They are thought to enter the earth's atmosphere from outer space. In the earth's atmosphere these primary rays are largely converted into secondary rays of less energy, such as mesons, positrons, high-speed electrons, etc. The intensity of cosmic radiation diminishes between the equator and the poles. This is believed to be due to deflection by the earth's magnetic field and would suggest that the primary cosmic rays reaching the earth are of positively charged particles, probably protons.

Some equivalent names (synonyms) as used in atomic physics.

α rays	—α particles: they are helium nuclei —helium ions.
β rays	—β particles: they are fast electrons.
Deuteron	—heavy hydrogen nucleus.
Electron beam	—stream of β particles.
Photon	—quantum (package) of light energy: particle of light.
Positive rays	—canal rays: they are of ionised gas molecules.
Positron	—positive electron.
Proton	—normal hydrogen nucleus: it is a hydrogen ion.
Radium emanation	—radon: it is the highest member of the series of inert gases in the Periodic Table of the elements. It is given off during the radioactive breakdown of radium, and is itself radioactive.

A HISTORY OF NUCLEAR PHYSICS

In 1896 Becquerel discovered that in the case of the metal element uranium both the element and its compounds continually give out rays which can pass through paper and thin foil and affect photographic plates. The work of the Curies soon showed that other elements of nearly the same atomic weight, such as radium and thorium, give off similar rays. For a while these rays, because of their penetrating power, were confused with X rays. But in 1899 Rutherford showed that the radiation from uranium could be split up by means of a magnetic field into three sorts of rays, which he named α, β and γ. The course of each stream was traced by the glow produced where it fell on a zinc sulphide screen. The beam which was not deflected by the magnetic field was called the γ ray and turned out to be a more penetrating form of X rays. The β beam, which was the one most deflected by the magnet, later was shown to be of negatively charged particles identical with the electrons of the cathode rays. It was the α stream, weakly deflected by the magnet, that proved to be the most puzzling. The direction of its bending showed it to be made up of positively charged particles. Alpha rays are given off from a number of radioactive substances, but their range (the distance from the source beyond which a fluorescent screen fails to detect them) and their speed at emission (of the order of 18,000 miles per sec.) differ according to the source of the rays. The elder Bragg, from a study of these ranges and the charge on the particles, which was measured as equal to two electron charges, suggested that the particles were helium ions (i.e. atoms of helium with two positive charges—i.e., lacking two electrons). Rutherford confirmed this with the ingenious apparatus shown in Fig. 1. The alpha particles (from radon gas) could pass through the thin-walled inner glass tube. Collected for a few days in the outer tube, the product was later driven up into the fine-bore tube and sparked—when the spectrum of neutral (atomic) helium was obtained. The alpha particles when or after they entered the outer tube must each have collected two electrons, becoming atoms of helium. A separate test showed that atomic helium, when put into the inner tube, could not escape through the thin glass wall. Thus the helium obtained in the first test could only have come from α rays passing through the wall of the tube.

When a beam of α rays falls on a fluorescent screen of zinc sulphide the collision of each α particle with the screen produces a tiny spark-like flash of light visible with a magnifying glass. You can see this for yourself if, in a blacked-out room, after resting your eyes, you look through a pocket magnifier at the hands of a luminous watch or clock. With little more technical resources than this, Rutherford in 1911 investigated the already known ability of α rays to pass through ultra-thin metal foils, such as of gold, silver, platinum, aluminium, etc. The way he arranged his material is shown in Fig. 2. The surprising thing is that a stream of positively charged particles should to so great an extent be able to pass unaffected through some 2,000 layers of metal atoms without difficulty or disturbance. It had been supposed that the inter-electron spaces of the atom were filled with

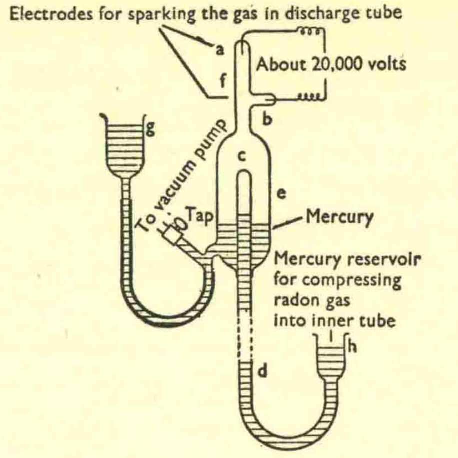


Fig. 1. *Apparatus to show that α particles are helium nuclei.*

(a) and (b) Electrodes for obtaining discharge from gas accumulating at head of tube (f).

(c) Very thin-walled glass tube (wall 1/100 mm. thick) into which the α ray source (as radon) is introduced via (d). (The source was radon gas—radium emanation.)

(e) Highly evacuated tube with thick walls (emptied via the γ tube and a vacuum pump) into which the α particles are able to pass. Helium cannot do this if placed in (c).

(g) Mercury reservoir when raised drives the gas accumulating in (e) up into the limb (f), where it is sparked, its spectrum proving it to be helium.

(h) Mercury reservoir for compressing radon gas into inner tube.

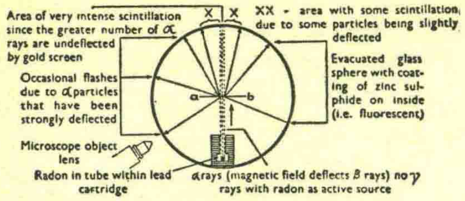


Fig. 2. *Rutherford's apparatus for the investigation of the passage of α rays through metal foils.*

(a) (b) = ultra-thin gold-foil screen; in thickness 6×10^{-5} cm., it represents about 2,000 layers of gold molecules.

Note: Before use the screen is tested for airtightness, i.e. to prove there are no small holes in it.

positive electricity to produce the neutral atom. In that case a continuous layer of atoms should act like a brick wall towards positively charged particles, except where an occasional particle might punch its way through by displacing or capturing a negative electron. But this is not the case. Very occasionally an alpha ray is subject to considerable deflection, as shown by rare scintillations all over the surface of the glass bulb; indeed sometimes to a larger angle than 90° (i.e. it is "turned in its tracks"). Thus though deflection is rare, when it does occur it can be considerable. All this led Rutherford to conclude that instead of being generally distributed the positive electricity of an atom is densely concentrated in a relatively minute nucleus at the centre of the atom. Lenard from his studies of the penetrating powers of cathode rays had made a more or less similar suggestion as early as 1903. The electrons, which the nucleus holds in virtue of its positive charge, are considered to be scattered around it at relatively great distances. Thus an atom is to be thought of as made up principally of space, a condition that would allow a very large proportion of all α rays falling on a foil to pass through unaffected. The mass or weight of the atom is also concentrated into this nucleus. In the case of the simplest atom, that of hydrogen, the nucleus is found to be 1,837 times as heavy as an electron, yet occupying only 1/10,000th part of the space inside the atom. This size difference has been compared with that of a fly in a house! (The nucleus of the hydrogen atom has been given a special name because of its fundamental importance. It is called a proton.) Should an α particle when passing through a metal foil chance to come very near to a nucleus, then, since the nucleus carries the mass and the positive charge of the atom, we would expect the α particle to be turned to one side, or even made to return on its course depending on the angle of collision. Rutherford's experiment shows that this is what does in fact occasionally happen.

Rutherford also showed that the amount of deflection experienced by α rays increases with the atomic weight of the metal used for the screen. From this fact a complicated calculation concludes that the charge on the nucleus must increase by one for every successive element in the Periodic Table (table of elements by atomic weight), the hydrogen nucleus carrying one positive charge.

X RAYS

When cathode rays are allowed to fall on to an element, either as a separate target or as the anode of the tube, X rays are generated. Moseley in 1913 showed that these could be resolved into characteristic spectra for each element by diffraction through a crystal of potassium ferro-cyanide. The wavelengths of certain lines in these X ray *spectra* decrease regularly with the increase in atomic weight. The decrease is even more closely related to Moseley's Atomic Number, a number calculated for each element, and ranging from 1 to 92 for the naturally occurring elements. The Atomic Number represents the number of electrons in the atoms of an element and it increases one unit at a time from hydrogen (= 1) upward. The X ray *scattering power* of thin films shows a further fact that each successive element in the Periodic Table has an increase of scattering power indicating the possession of one additional electron.

A THEORY EMERGES

From such facts the conclusion is reached that the atoms of all the elements must be composed of positive nuclei and negative electrons. One element differs from another in the number of positive charges on its nucleus, which in turn is equal to the number of electrons in the atom. At first, under the influence of ideas borrowed from Newton's system of mechanics, it was considered that the electrons must move round the nucleus in planetary orbits. Thus arose Rutherford's idea of the planetary atom, further developed in 1913 by Niels Bohr when working with Rutherford in Manchester. But in order to explain why, in what is an *electromagnetic* (not a gravitational) solar system, the electrons do not fall into the nucleus, Bohr departed radically from Newtonian mechanics by suggesting that only *certain* electron orbits round the nucleus are possible. From observations of various peculiarities in the radiation of heat by hot bodies Max Planck had recently concluded that atoms only radiate energy in gushes, or quanta. When Bohr in 1922–5 extended his picture of the hydrogen atom to cover the periodic system of the elements his interpretation also had the immediate advantage that it could explain why energy is radiated by atoms in stepped amounts, or quanta. The sudden jumping of electrons from one possible orbit to another possible orbit will result in the liberation of a fixed amount of energy depending on which orbits are involved. By quantum theory this amount then fixes the wavelength of the light given out. To agree with the evidence of X ray spectrum lines, the electron orbits are further grouped into sets or shells. The electrons of the outermost shell of any atom are the exchangeable valency electrons. A shell of eight electrons in this region can be shown to be a stable arrangement. Since the gases of the helium-radon series of the Periodic Table, with the exception of helium, have this condition, they show no valency, i.e. are inert, unreactive. Helium itself is a special case, having a stable arrangement of two electrons in a single shell. Although the planetary idea of atomic structure has now been superseded by a mathematical wave-mechanical description that cannot be visualised as a model (just as Newton's mechanics has been superseded by Einstein's Relativity Theory) the Bohr atom is still a very useful idea.

MORE FACTS COME TO LIGHT

Continuing his painstaking observation of the scintillations produced by α rays Rutherford began examining more closely the features of their passage through gases, as distinct from through metal foils. He carefully measured the various ranges they had

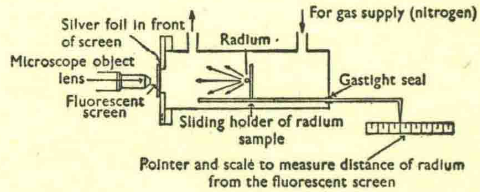


Fig. 3. *Apparatus with which Rutherford first detected the transmutation of atoms by α ray collision (a modification of Crookes' spinthariscope).* Range of alpha rays through gas and silver foil = 7 cm. But when radium is removed to distances up to 40 cm. from the screen occasional (very rare) scintillations still occur. These cannot be due to alpha particles, as the range is too great. They are due to fast protons.

in air and other gases, using the simple instrument shown in Fig. 3. In 1919 he was able to show that normally when the source is removed from the screen to a distance greater than the range of all the α particles (= 7 cm. allowing for the effect of the silver foil in front of the screen) scintillation stops abruptly. But when the chamber contains only pure nitrogen gas, some very rare scintillations can be obtained at distances as great as 40 cm.! It is as though some process is boosting the α particle effect. The energy properties of these new rays could not be determined experimentally, as it could not be known at what place in the chamber they originated. Rutherford considered it likely that a *head-on* collision between a swift α particle and the nucleus of a lightweight element could result in the α particle approaching extremely close to the nucleus, or even penetrating it. The result of such profound disturbance might be disintegration, i.e. transformation of the nitrogen nucleus into one of another sort. Theoretical considerations suggest that this would be an oxygen nucleus since (although the nitrogen atmosphere was free from atomic hydrogen) the range of the new emitted particles was consistent with their being fast hydrogen nuclei (protons). Nitrogen atom + Helium nucleus (α particle) = Oxygen atom + Hydrogen nucleus (proton) (if calculated on the weight or charge basis). Rutherford later secured a similar emission of hydrogen nuclei from bombarded aluminium on its transmutation into silicon.

At about this time the Wilson cloud chamber (used first by J. J. Thomson in 1899) was much improved in its stability and its illumination, so that the water droplet trails left by ionising particles would persist long enough to permit their being photographed. Its operation is synchronised with that of two cameras, so that photographs are only taken when ionising particles are in the chamber. With two cameras, from the stereoscopic effect, the exact placing in space of any track can be worked out.

NUCLEAR COLLISIONS ARE WATCHED

With this potent new instrument P. M. S. Blackett was able, in 1922, to secure clear photographs (Fig. 4) of collisions between α particles and nitrogen nuclei. Application of a strong magnetic field to the cloud chamber indicated that the particle emitted after such a collision was positively charged, whilst other measurements of its track confirmed that it was a hydrogen nucleus (i.e. an ionised hydrogen atom)—now known as a proton. Thus was Rutherford's brilliant interpretation of his results vindicated visually.

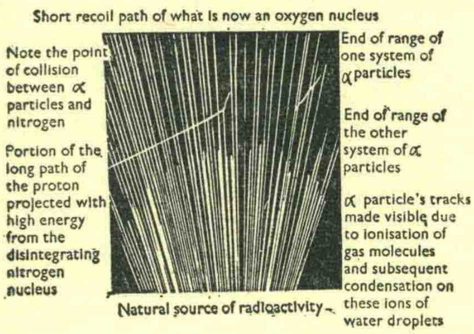


Fig. 4. *Transmutation (disintegrating collision) between an α particle and a nitrogen atom in a cloud chamber* (nitrogen was in the cloud chamber atmosphere). Note the two ranges of α particles due to the use of a mixed source of α particles (i.e. a natural mixture of two radioactive substances each giving α particles of distinctive range).

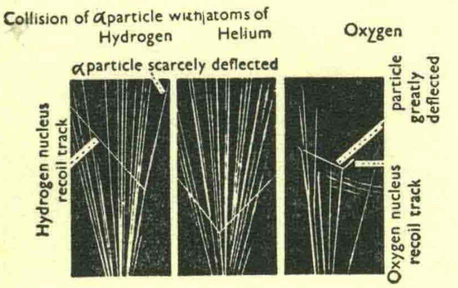


Fig. 5(a) Fig. 5(b) Fig. 5(c)

The proton ejected in this *disintegration* emerges with great velocity, sometimes at right angles, or at an even smaller angle, to the α ray. This is very different from what is seen in other photographs

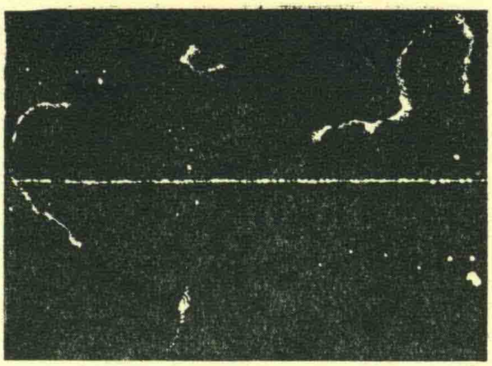


Fig. 6. *Cloud chamber tracks of β rays.* The long straight but very narrow path is of a fast beta ray, probably from cosmic radiation. These have ranges much larger than alpha rays and for this reason their ranges are often measured in aluminium where they are much shorter than in air. The shorter (about 1 cm.) curving paths are of slow beta rays ejected from gas molecules by the passage of a gamma ray. Being slower, they are more easily bent by collision with molecules of the gas, to which they more easily lose energy in ionisation, thus producing noticeably thicker droplet tracks.

which Blackett obtained, in the same way, of *simple* (elastic) *collisions* between α particles and the nuclei of various gaseous elements, including nitrogen. These collisions are of the same sort as those we have seen experienced by some alpha particles in going through a gold foil. They are called elastic because the observed effects are in accordance with the mechanical laws of elastic collision that govern the colliding of such things as billiard balls. In these cases a light body hitting a heavy one transfers only a little energy to it, thus making it move only a little. But it is itself deflected or reflected appreciably (e.g. a golf ball hitting a cricket ball). Where the weight difference is less the energy transfer is greater and the struck ball moves more and the striking one is slowed down relatively more. This sort of thing is seen in Fig. 5c, where, after colliding with an oxygen nucleus, the α particle continues for only a short distance on its new deflected course (= the longer arm seen in figure) and the oxygen nucleus recoils only slightly. The result of collision with a helium nucleus of its own weight (Fig. 5b) is that the deflected path of the α particle and the recoil of the helium nucleus are approximately equal. Similar conditions apply to collision with a hydrogen nucleus (Fig. 5a).

Fig. 6 shows a cloud-chamber track (= the straight track) of a fast β particle, similar to those in β rays, but here probably derived from cosmic radiation. Notice how very small and widely spaced are the water droplets. This is because fast-moving electrons, despite their considerable energy, have only slight ionising power. Their ionising power is small since they spend so short a time in the field of any other electron in the medium through which they pass. The curving tracks in this figure are of slow-moving β particles. Here the tracks are noticeably thicker and more continuous, and they become more so towards the terminal point of each track. These slow β particles are clearly seen to be more often deflected out of their course with consequently more rapid loss of energy.

SOME PROBLEMS SET BY THE NUCLEUS

We have seen that for any element the Atomic Number represents the number of positive charges carried by the nucleus, which is also equal to the number of planetary electrons. But inspection shows that the Atomic Number is only equal to the Atomic Weight in the case of hydrogen. In other cases the Atomic Number is always smaller than the Atomic Weight, and as we proceed to the heavier elements the difference increases rapidly (Uranium A^t W^t = 238. A^t N^o = 92). To make up the nuclear mass to the atomic weight, without increasing the charge beyond that set by the Atomic Number, the nucleus needs to contain additional particles possessing weight but no charge. From the evidence of atomic disintegration the charged particles of the nuclei of all the elements are supposed to be protons (hydrogen nuclei) of mass 1, charge 1. In 1920 Rutherford supposed that the mass-bearing uncharged particle might be a proton, the charge of which was neutralised by a non-planetary electron. He suggested for it the name "neutron". It still remained necessary (1) to discover the proposed neutral particle and (2) to explain why the whole nucleus is, in general, a stable structure. Remember that in all the elements except hydrogen the nucleus contains several or many positive charges—which should repel each other—all situated within a very small space!

If the *cathode* of a cathode ray tube is made with a hole through it luminous rays pass backwards through the hole. These are called positive rays, or canal rays. In 1898 J. J. Thomson, using photographic plates to detect the path of the rays, showed them

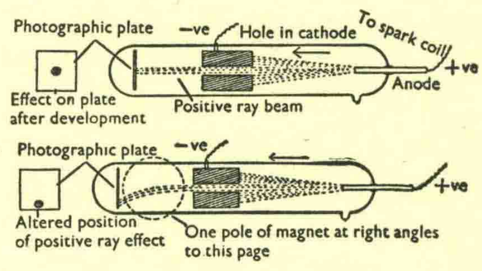


Fig 7(a) (above) *Positive ray of cathode ray tube.* Fig. 7(b) (below). *Positive ray bent by a magnetic field.*

to be deflected by magnetic and electric fields in a way that revealed them to be composed of positively charged particles (Figs. 7a and b). The value of e/m (charge/mass) of these particles can be calculated from the amount of bending they undergo in a known strength of field, from which it appears that they are positive ions of the gas (at low pressure) in the tube. Whilst making

measurements with neon in the tube Thomson (1910) found that the rays when magnetically deflected separated out into *two* streams, which gave two "lines" on the photographic plate. The position of these lines indicated particle weights of 20 and 22. (The lighter particles, being faster, are deflected less by the field.) The atomic weight of neon as ordinarily determined is 20·2. Thomson suggested that this figure could be the result of ordinary samples of neon being mixtures of two "elements". Aston developed this positive-ray apparatus into the mass spectrograph (Fig. 8) with which, between 1922 and 1924, he showed that many other elements exist in two or more forms differing in atomic weight.

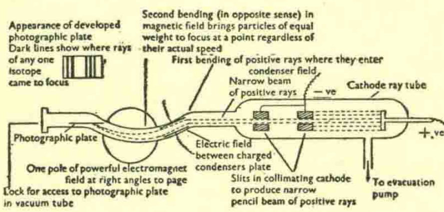


Fig. 8. *Mass spectrometer (Aston's) for isotope separations.*

Soddy had observed a similar situation in the case of two forms of a radioactive element of differing stability both occurring in connection with the same place in the Periodic Table. He called these forms isotopes (= "same place" in Greek). Their existence explains why the atomic weights of elements so commonly prove not to be whole numbers although whole numbers might have been expected on the nuclear theory of the atom. Since the isotopes of any element have the same Atomic Number, their nuclear charges and their planetary electron systems are alike. In consequence they behave alike chemically, and cannot be separated by chemical means. Their difference in atomic weight must be due to differences in the proportions of the neutral particles in the nuclei. Aston also showed that hydrogen (A^t $W^t = 1$) contained a heavy isotope (A^t $W^t = 2$), to the extent of 1 part in 4,000. In 1932 Urey, by the process of fractionally distilling a large amount of liquid hydrogen, succeeded in isolating heavy hydrogen, which is now known as deuterium (its nucleus = a deuteron) (*see glossary*). Subsequently other workers isolated heavy water (remember water is H_2O). It was found to be 11% more dense than ordinary water. These discoveries were to affect very greatly the development both of ideas and technical resources in nuclear physics.

NEW AND IMPROVED TOOLS

Technical developments soon made possible the use of artificially accelerated particles to supplement those from natural radioactivity. In 1932 Cockcroft and Walton at Cambridge produced the first artificial disintegration, breaking up the lithium nucleus into two alpha particles as the result of collision with an accelerated proton. Accelerating machines depend upon the development of high voltages. Cockcroft and Walton got theirs by means of an ingenious arrangement of condensers and rectifiers providing 700,000 volts D.C. This they applied in several stages to a source of protons by means of tubular electrodes. In the same year Lawrence in America developed in the cyclotron a system of intermittent circular acceleration in a magnetic field. A limit is set to the possible acceleration in cyclotrons when the accelerated particles begin to approach the speed of light. In the more recent synchrotron (1945) this limitation is overcome by applying frequency modulation to the power supply that feeds the accelerating electrodes. As a result particle streams of *extremely* great energy are obtained. As well as improved "guns" the nuclear research worker now had an increased variety of "bullets". Besides the old α particles and electrons it became possible to have beams of high-speed protons, deuterons, and neutrons, the latter being particles of a new sort to be described later. In addition to using the cloud chamber it was found possible to record the tracks of many of these particles by passing them through the emulsion of specially prepared photographic plates.

MORE CONFIRMATION OF THE NUCLEAR THEORY

In 1930 it was found that, when bombarded by alpha particles, the element beryllium gives off rays even more penetrating than the γ rays of radium. In 1932 Chadwick showed that the observed results are most satisfactorily explained in terms of an α particle entering a beryllium nucleus, forming an unstable complex which disintegrates at once into a carbon nucleus and at the same time liberates *not* a γ ray, but a particle of previously unknown kind. The new particle had the mass of a hydrogen nucleus (proton of mass 1), but carried no charge. It was the neutron, whose existence had been foreseen by Rutherford in 1920. The very penetrating nature of these particles from beryllium is due to their uncharged state, as a result of which they are not subject to electrical repulsion either by electrons or nuclei. Since they produce no ionisation and thus leave no tracks in the cloud chamber, the original confusion with γ radiation is understandable. The Joliots had found in 1931 that the rays from beryllium (not then known to be composed of neutrons) showed an increased ionising effect when passed through paraffin, or other hydrogen-containing material, before entering an ionisation chamber. This strange effect is now known to result from a slowing down of the neutrons in these substances. Slow neutrons are more readily captured by nuclei than are fast neutrons. Thus, in the atomic bomb the large-scale liberation of atomic energy by the chain reaction of a uranium isotope of atomic weight 235 is triggered off by the introduction of neutrons previously slowed by passage through heavy water, or very pure graphite.

THEORIES ARE AGAIN CONFOUNDED BY THE FACTS

Just when the substances of nature looked like being resolved into patterns of protons, neutrons and electrons, the picture once again became confused. Not only did fresh discoveries, both mathematical and experimental, reduce the sharp division between particles and radiations, but fresh attention given to the structure of nuclei brought to light a whole crop of new particles—including positive electrons! In 1935 Bohr had shown on theoretical grounds that the elements at each end of the Periodic System are inherently unstable. Many of the heavy ones undergo radioactive disintegration (i.e. flying apart) in varying degrees. The lighter elements, it was shown, must be considered as possessing a tendency towards transmutation by a process of fusion (i.e. running together). Both groups can provide the basis for vast energy production in the course of these nuclear disturbances. Yukawa, in the same year, was led by other theoretical considerations to predict that in the course of such nuclear disintegrations part of the *force* involved in holding together the particles of the nucleus would be set free as other *particles*! These would have mass intermediate between protons and electrons. Two years later, in 1937, investigations into the effects of cosmic radiation (*see* p. 92) revealed the production, both in cloud chambers and in photographic plates, of such particles. They are formed only when atoms are bombarded by rays of *very* great energy, and they were named mesons. Mesons have also been produced artificially in the cyclotron. Careful examination has shown that mesons of different masses can occur. Those best known are about 300 times the weight of an electron (protons, remember, have nearly 2,000 times the mass of the electron). Positive and negative forms of mesons have been seen!

We have already seen that during radioactive disintegration electrons of high velocity (β rays) are shot out of atoms. The great velocity with which they emerge (from 62,000 to 180,000 miles per sec.) shows they have come from the *nucleus* and not from the planetary orbits. This is confirmed by the fact that a nuclear disintegration in which a β ray is emitted always produces a new nucleus of atomic number one unit greater than the original. This is what would be expected if the *nucleus* had lost an electron. In 1932 Anderson showed that cosmic radiation occasionally liberates *positive* electrons (called positrons) from nuclei lying in its path. Often these positrons are liberated as members of what are called positron/electron pairs (Fig. 9). Presumably these nuclear electrons exercise some role of binding together the other nuclear particles.

The more precisely we seek to describe what the world is made of, the more complex and incomprehensible the problem seems to become! It is now more than ever evident that matter is a remarkable and still mysterious phenomenon. Yet though its properties have proved to be too complex for picturing in any atomic model, its behaviour does seem capable of being described in mathematical equations.

In this account of the last sixty years of research in atomic physics we have been

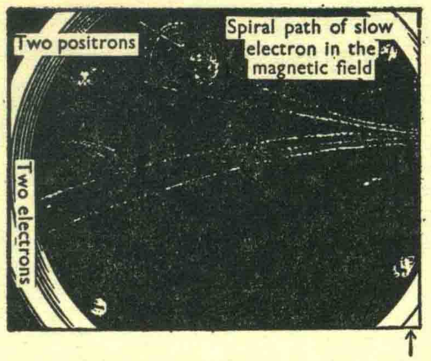


Fig. 9. *Cosmic ray production of two positron electron pairs in the wall of the cloud chamber.*

able to show little more than the outside of the edifice of knowledge which patient and ingenious research has erected.

Conclusions that now seem obvious and inevitable seemed contradictory, or even crazy, at the time when the discoveries were first made. It is for that reason you will find, on page ninety-two, a table setting out the different names (synonyms) that were given to the same happenings before experimental demonstration made clear beyond doubt they were one and the same.

Glossary

Accelerator An apparatus used to produce high-speed particles.

α (alpha) particle A particle emitted by many of the heaviest radioactive atoms. It consists of two protons and two neutrons and is identical with the nucleus of helium, $_2He^4$; it carries two units of positive charge.

α (alpha) ray A stream of α particles.

Atom The smallest unit from which the chemical elements are made. It cannot be modified by chemical means.

Atomic bomb An explosive device that relies upon the fission of heavy elements for its power.

Atomic number (symbol: Z) A number assigned to an element and equal to the number of protons in the nucleus, and to the number of orbital electrons flying round the nucleus.

Atomic weight The "weight" assigned to an element; it enables the weights of various atoms to be compared. The standard for chemical purposes is based on a weight of 16.000 for the average weight of the isotopes of naturally occurring oxygen; the physical standard is based on a weight of 16.000 for the $_8O^{16}$ isotope.

β (beta) particle An electron emitted from the nucleus of a radioactive atom.

β (beta) ray A stream of β particles.

Betatron An accelerator for β particles.

Bohr atom (or Bohr-Rutherford atom) The atom pictured as a small positively charged nucleus around which move the electrons in orbits. The movement of an electron from one orbit to another is accompanied by the emission or absorption of electromagnetic radiation.

Breeding The process whereby more fissile material is produced by a reactor than is consumed in the primary reaction.

Chain reaction A process wherein the products are able to initiate further similar processes and so produce a sustained reaction.

Cloud chamber An apparatus for studying the paths of charged particles.

Critical mass The smallest weight of fissile material in which a self-sustained chain reaction can occur.

Curie A unit of radioactivity, equal to $3{\cdot}7 \times 10^{10}$ disintegrations per second.

Decay The decrease in the number of atoms of a radioactive substance on account of the disintegration of the atoms.

Deuterium Heavy hydrogen, $_1H^2$; sometimes given the symbol D.

Disintegration A change in the nucleus of an atom that results in the production of a new atom; it is frequently accompanied by the emission of particles and γ (gamma) rays.

Electron The smallest negatively charged particle.

Element A substance that cannot be simplified by chemical means.

Elementary particles Those particles that cannot be further subdivided, e.g. electrons and protons.

Fission product One of the two atoms produced when a heavy atom such as U 235 undergoes fission. Isotopes of all elements with $Z = 32$ to $Z = 58$ have been identified in mixtures of fission products.

Gamma ray (γ ray) Electromagnetic radiation emitted by a nucleus when it rids itself of an excess of energy after a nuclear reaction or disintegration.

Geiger-Mueller counter A detector of ionizing radiations. Its operation depends upon the production of an avalanche of electrons by multiple collisions after the generation of relatively few ion-pairs by the original particle or γ (gamma) ray.

Half-life The period during which the number of atoms of a radioactive substance decreases by one half.

Heavy water The oxide of deuterium D_2O. Water with deuterium substituted for hydrogen.

Ionizing radiations Radiations from a radioactive substance. When a fast-moving particle from a radioactive substance dislodges an electron from the atoms of a gas through which it moves, the dislodged electron and the now positively charged atom (*ion*) are called an *ion-pair*. Thus ionizing radiations.

Isotope Used to describe the various atoms that make up an element. All the isotopes of a given element have the same value of Z but may differ in the number of neutrons that they contain.

Labelling The use of radioactive isotopes to render materials normally chemically inactive (or nearly inactive) readily detectable by using nuclear particle detectors. Also used to describe the analogous use of stable isotopes, which are measured in a mass spectrometer. The technique is very useful for following the course of chemical and physical reactions.

Mass The mass of an object is a measure of the amount of matter that it contains. The units in which it is measured are the same as those for weight. For practical purposes mass and weight may be regarded as equivalent.

Mass defect The difference between the mass of an atom and the mass of its component parts.

Mass spectrometer An apparatus in which ions are separated in a manner dependent upon their masses.

Meson A generic name for a group of sub-atomic particles. They have masses some hundreds of times that of an electron but less than that of a proton.

Moderator A material used in a nuclear reactor to slow down the neutrons and so make more easy the propagation of the chain reaction.

Multiplication factor (symbol: k) The number of neutrons produced, on average, in the fission of one atom, that can produce fission in a further atom. $k = 1$ in a reactor operating at a steady power level.

Neutron A sub-atomic particle. Its mass is slightly greater than that of the proton. It is a constituent of all nuclei except that of hydrogen, $_1H^1$. It is of very great importance in the production of power by nuclear fission, for it is the agent responsible for the propagation of the chain reaction.

Nucleus The central positively charged core of an atom. Its volume is about only one thousandth that of the whole atom; nevertheless virtually all of the weight of the atom is concentrated in it.

Photon A beam of light or other electromagnetic radiation is sometimes said to consist of a stream of particles called photons.

Plutonium An element with the atomic number 94. All the isotopes are radioactive and only minute amounts of it are found in nature. Relatively large amounts of $_{94}Pu^{239}$ are formed in reactors containing U 238.

Positron (symbol: $\beta+$) A sub-atomic particle identical with the electron, or β particle, except for its charge, which, although equal to that of the electron, is positive. It is very short-lived.

Proton A positively charged sub-atomic particle. Protons with neutrons form the nuclei of atoms.

Radiation A general term to describe streams of particles or rays from radioactive elements or accelerators.

Reactor A term that has largely replaced the older "pile". It is an apparatus in which a controlled nuclear chain reaction occurs. Besides producing power, a reactor may be used to make radioactive materials, and plutonium. Thermal reactors depend upon the use of a moderator to slow down the neutrons. In fast reactors the chain reaction is propagated by fast neutrons in fuel rich in fissile material.

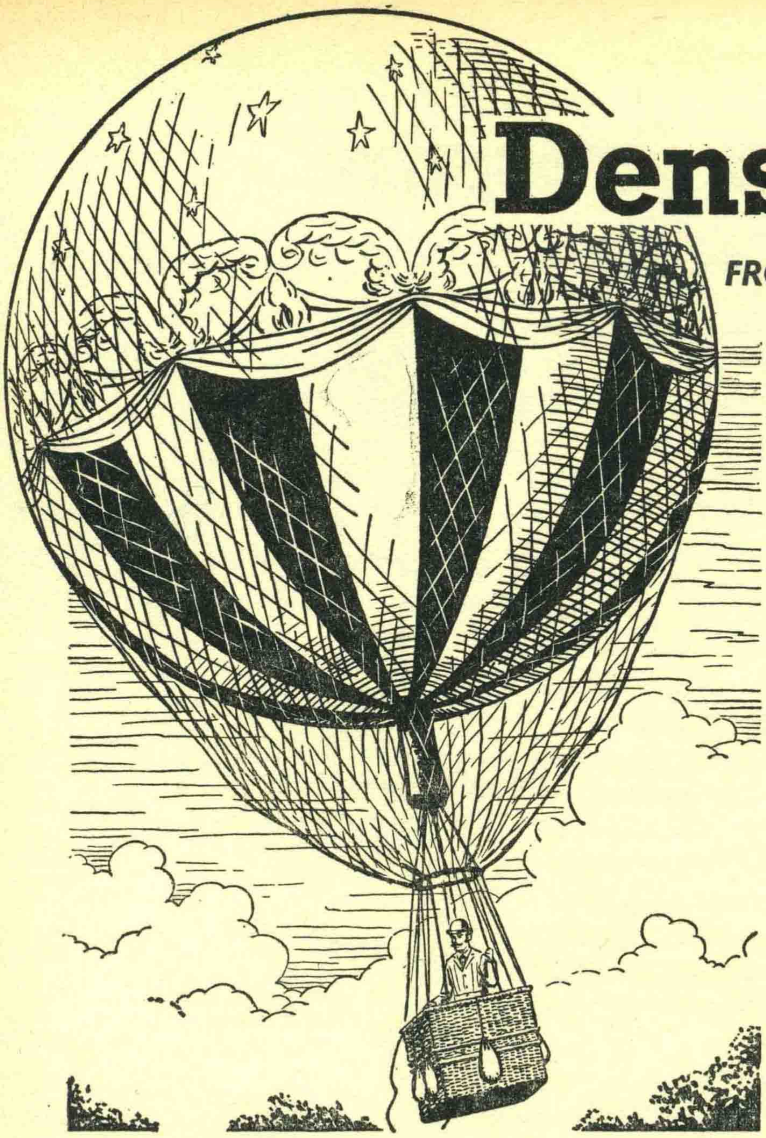
Scaler An electronic apparatus used to count the electrical impulses from detectors. Some scalers can count many thousands of impulses in a second.

Scintillation counter A detector in which the particles interact with a material with the emission of light, which is recorded by a photocell or photomultiplier.

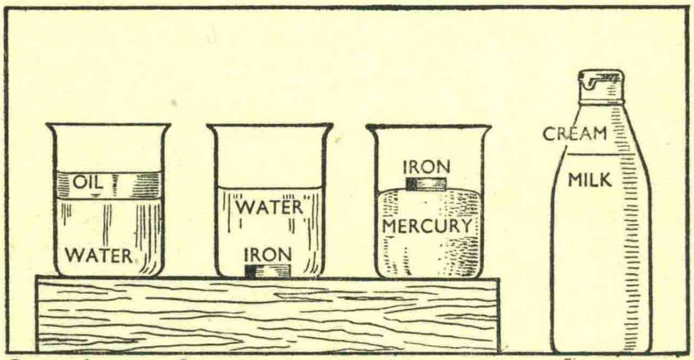
Tritium The isotope of hydrogen with a mass number of 3; $_1H^3$. It is radioactive, emits β particles, and has a half-life of about twelve years.

Density Physics

FROM BALLOONS TO BATHYSCAPHES

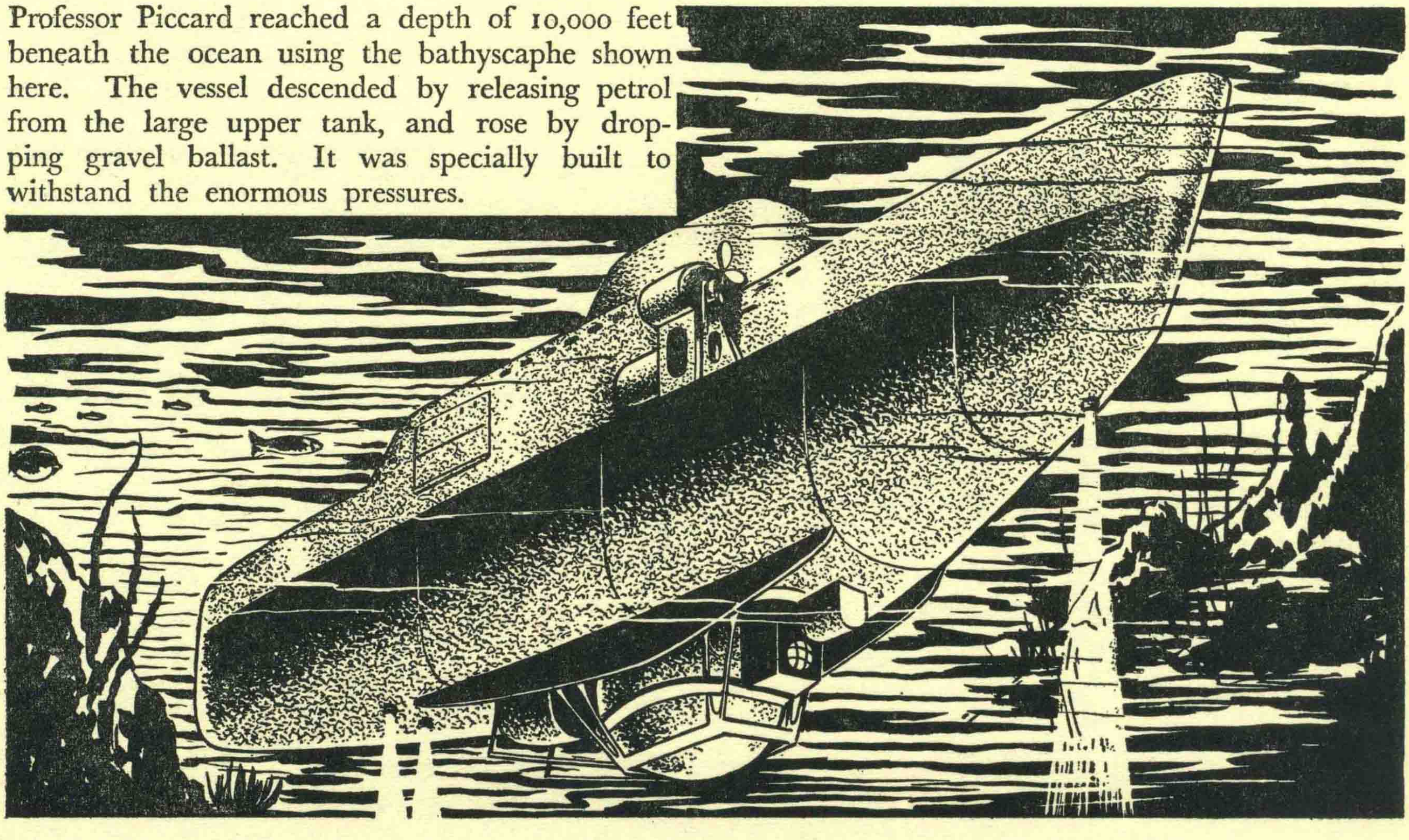


Even when loaded, the balloon is lighter than the air its large envelope pushes aside or "displaces". Cool air is surprisingly heavy: a cubic foot of it (about the size of a biscuit tin) weighs rather more than one ounce. Hot air is less dense than cold air (page 61) and so a balloon filled with hot air rises in the buoyant cooler atmosphere. Hydrogen gas is the least dense substance known; it would be an excellent material for filling balloons and airships but for its highly inflammable nature.

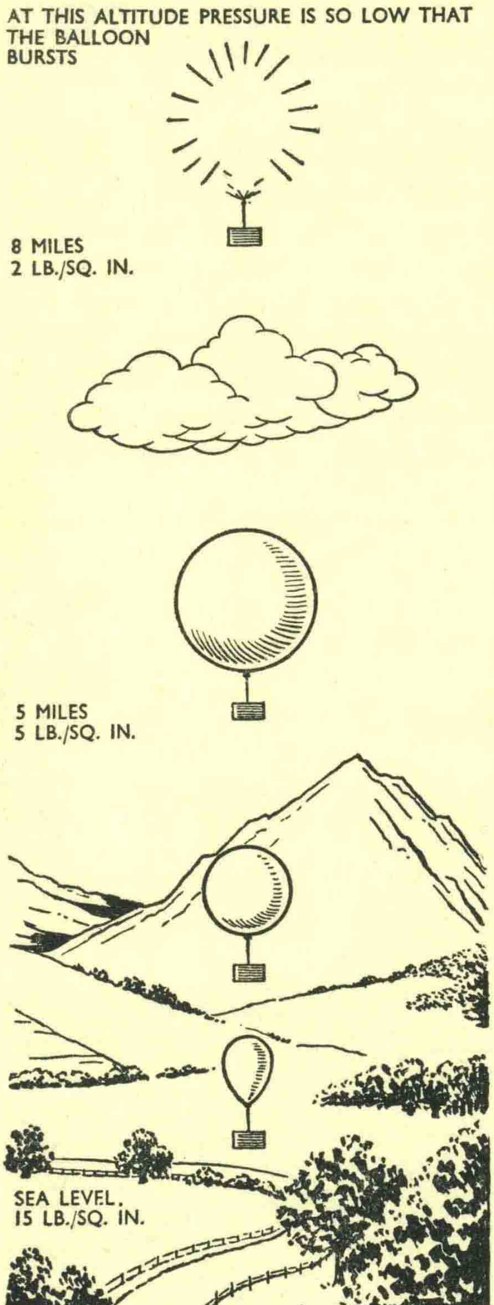


One substance floats on another of greater density. Cream is not as dense as milk. Iron sinks in water but will float easily on the denser mercury.

Professor Piccard reached a depth of 10,000 feet beneath the ocean using the bathyscaphe shown here. The vessel descended by releasing petrol from the large upper tank, and rose by dropping gravel ballast. It was specially built to withstand the enormous pressures.



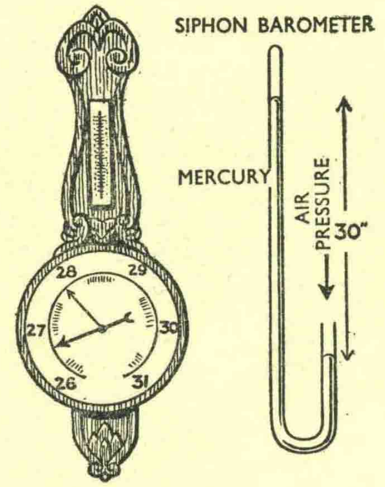
Atmospheric Pressure



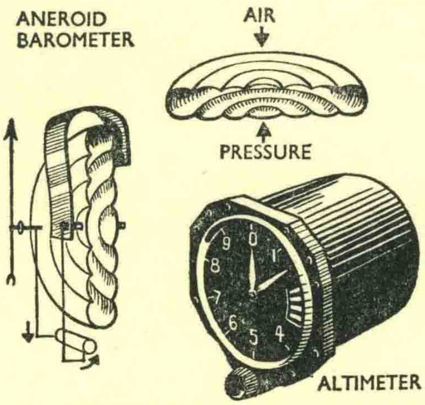
Instruments carried by the balloon are brought to earth by parachute.

Air has weight. Like everything else, the atmosphere is pulled by the force of gravity towards the centre of the earth. The effect of this force acts not only downward but in all directions because air is fluid. (In the same way Plasticine is squashed out in all directions when pressed.) The weight of the air acting on every square inch at sea level is about fifteen pounds, so a human being bears a load equal to that of two buses. The pressure of the atmosphere decreases as we rise above sea level and increases if we go into a deep mine. Aeroplanes flying at great heights have sealed cabins to maintain a comfortable pressure inside. The balloon on the left is not fully inflated at sea level. As it rises there is less and less pressure acting on it; the gas inside expands until the envelope bursts.

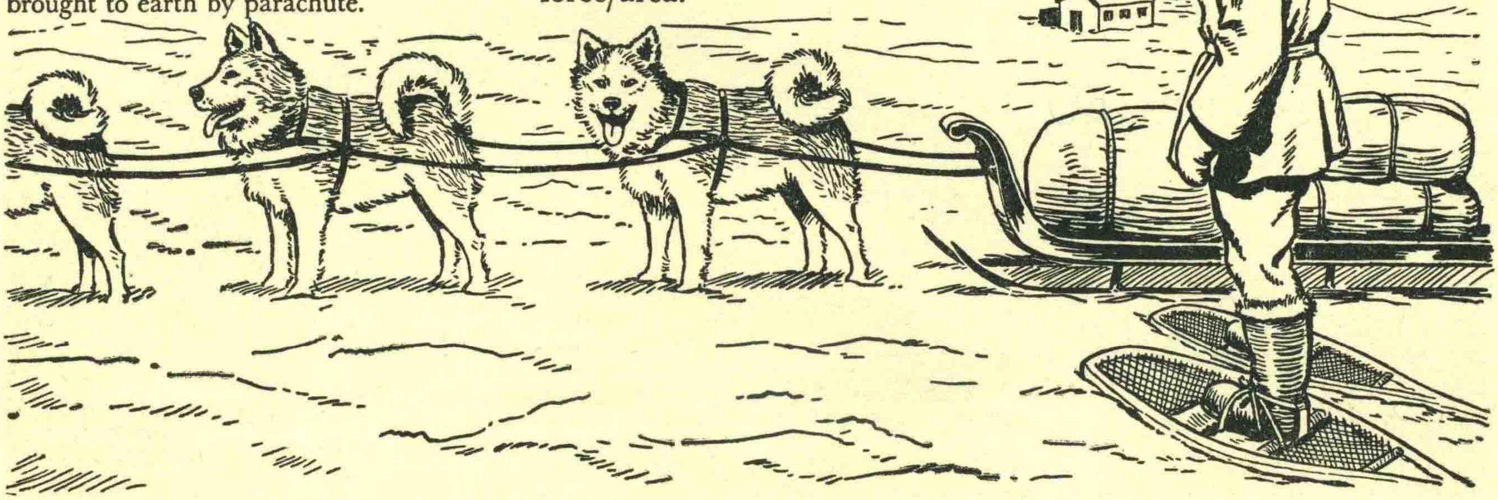
This variation of air pressure with altitude is employed to measure heights. The altimeter is an aneroid barometer marked off in feet instead of pressure units. It must be set at zero while the aircraft is on the ground.



The pressure of the air changes with weather conditions. That is why a barometer is used as a "weather glass". The figures on the dial are inches of mercury.



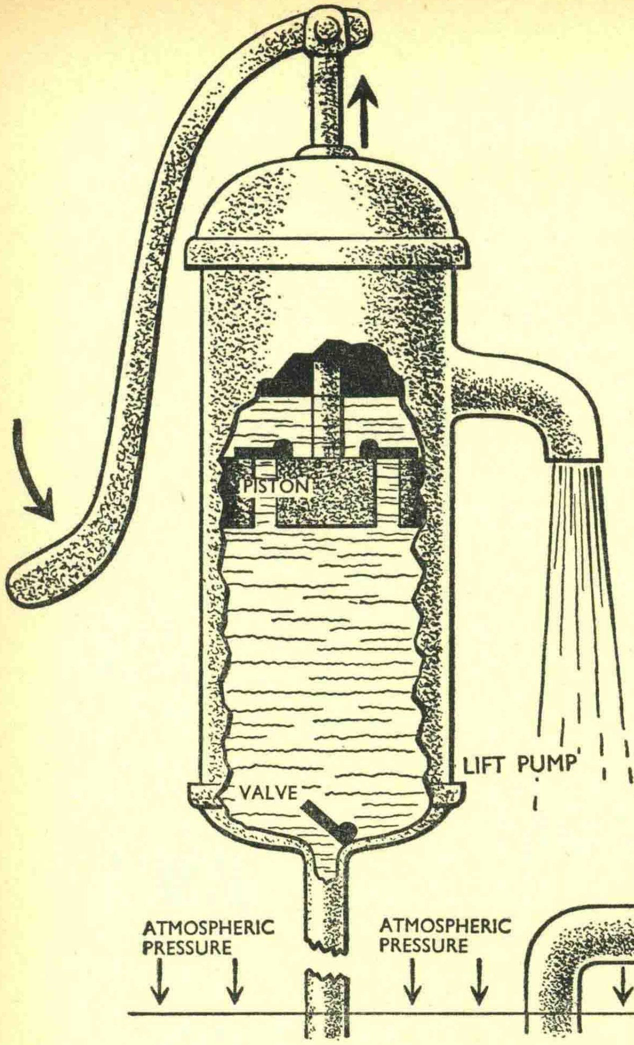
When wearing snow-shoes the man makes less impression on the snow because his weight is spread over a larger area. The greater the area, the less the pressure. Pressure = force/area.

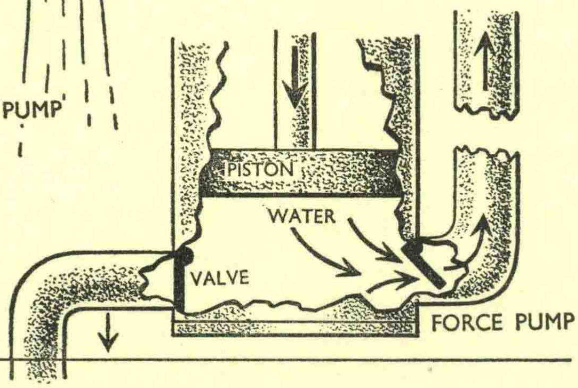


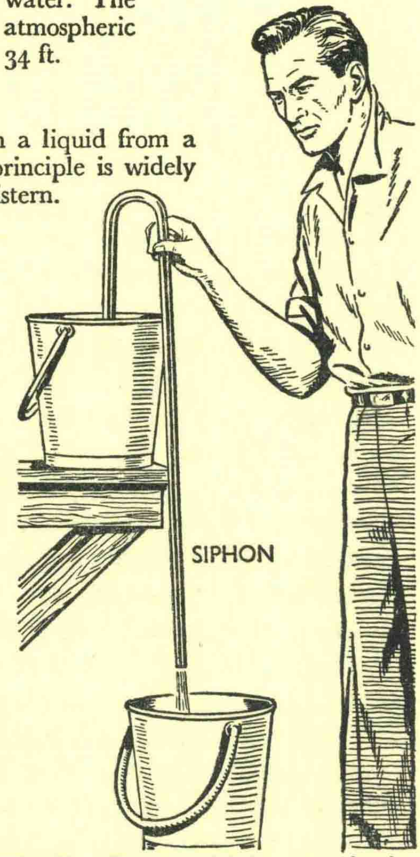
PUMPS AND SIPHONS

The atmosphere exerts a pressure of roughly 15 lb. per sq. in. This is equivalent to the weight of a 30 in. column of mercury or a 34 ft. column of water. The siphon and the pump (left) depend upon atmospheric pressure and cannot raise water more than 34 ft.

Although it is not possible to siphon a liquid from a lower to a higher level, the siphon principle is widely used in such devices as the lavatory cistern.

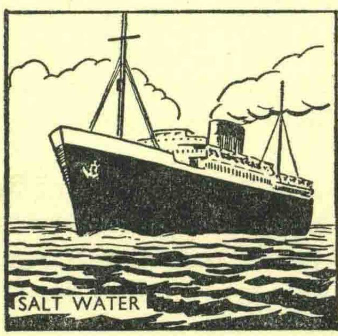


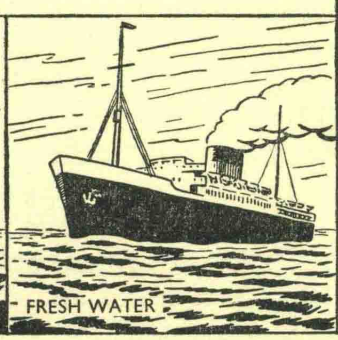


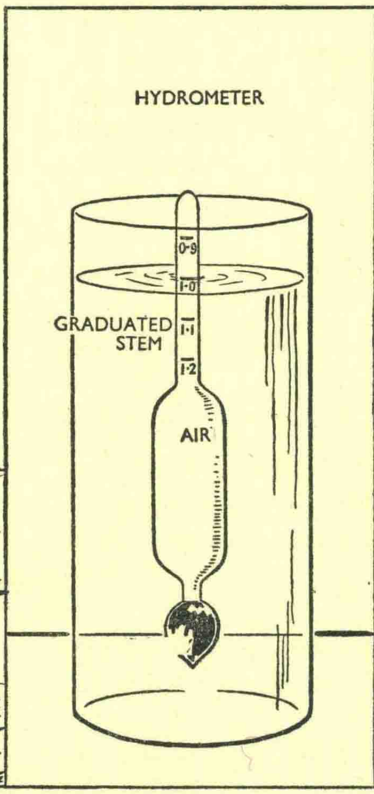


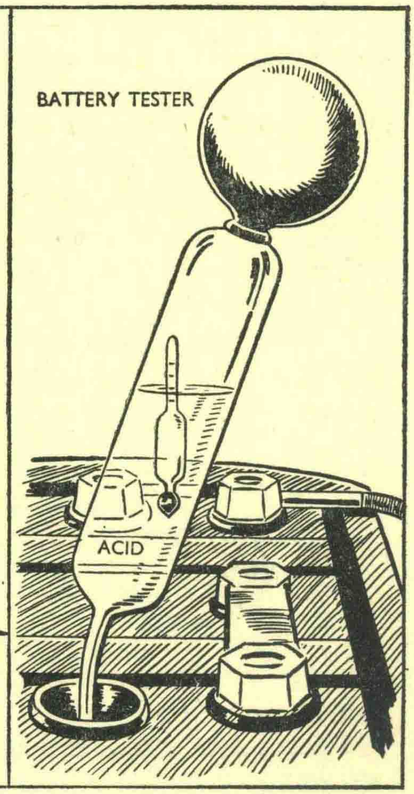
Raising the piston in the *Lift Pump* creates a partial vacuum in the cylinder below it. The atmospheric pressure pushing down in the well forces water up into the cylinder to fill this vacuum. Valves in the piston allow water to pass above it on the downstroke, and to be lifted bodily as the next upstroke creates a new vacuum. The *Force Pump*, which has no valve in its piston, is used to raise water to any height so long as the pump itself is less than 34 feet from the level of the water in the well. By adding an "air-dome" to the outlet pipe a steady flow is obtained.

When an object floats it displaces its own weight of fluid. The ship on the left is sailing in salt water; on the right, in fresh water, it is much lower in the water. Suppose the ship weighs 5,000 tons; 5,000 tons of salt water occupy far less volume than the same weight of fresh water, so a much smaller volume of the ship has to be immersed in salt water to displace the necessary 5,000 tons. For the same reason a *hydrometer* floats higher in denser liquids and is used to read off the density directly from markings on the stem. Lead-shot in the bottom of the air-filled tube keeps it upright.
The battery tester (right) contains a small hydrometer. The density of the acid in an accumulator is a reliable indication of its state of charge.









SOLIDS, LIQUIDS AND GASES

The molecules which make up a solid like iron are so tightly packed that they touch each other and cannot move from their fixed positions. That is why a solid has a definite shape. We would be very surprised if an iron nail suddenly changed into a ring, but we are familiar with the fact that a drop of liquid such as water spreads out on a table. The molecules in a liquid are able to move about and they are not tightly packed. In a gas, such as steam, the molecules are so widely spaced that they only occasionally collide even though they rush about at very high speeds.

A pound of water when boiled away gives exactly a pound of steam. However, it is plain to anyone who has watched a kettle boil that one pint of water does not produce just one pint of steam. The molecules have separated to occupy about 2,000 times as much space, or *volume*, as they did in the form of water. This means that a pint of water is thousands of times as heavy as a pint of steam. Can we say that water is heavier than steam? No, this is like saying that lead is heavier than feathers: a drop of water does not weigh as much as a roomful of steam, and a sackful of feathers weighs more than a scrap of lead. It is true that 1 pint of water is heavier than 1 pint of steam, or 1 cubic foot of water is heavier than 1 cubic foot of steam, or 1 cubic centimetre (c.c.) of water is heavier than 1 c.c. of steam, or, as the scientists put it, water is *denser* than steam.

The mass of 1 c.c. or 1 cu. ft. of a substance is called its *density*.

A very useful definition of density is given by the following equation:

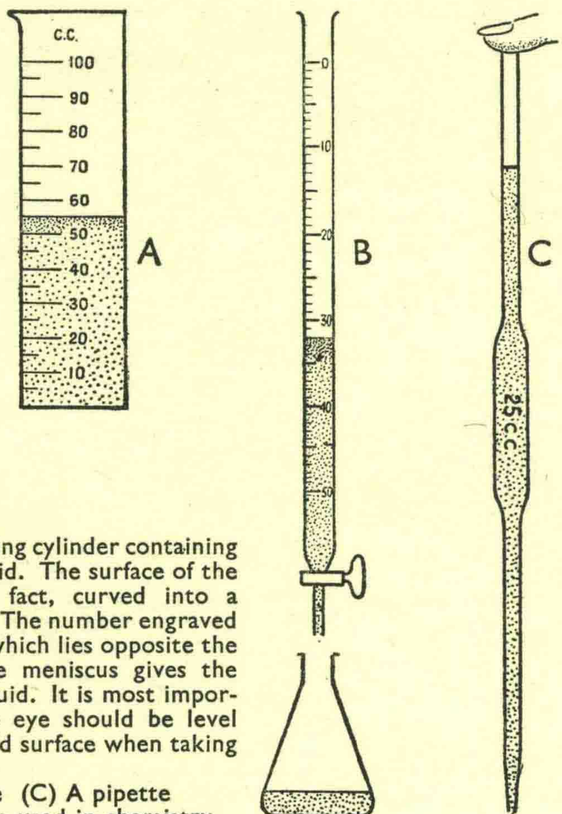
$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

It enables us to calculate the density of a substance by measuring its mass and dividing by its volume.

The mass can be measured easily on a spring balance, or, for greater accuracy, on a beam balance.

There are various ways of measuring a volume.

MEASURING INSTRUMENTS FOR LIQUIDS



(A) A measuring cylinder containing 55 c.c. of liquid. The surface of the liquid is, in fact, curved into a "meniscus". The number engraved on the glass which lies opposite the centre of the meniscus gives the volume of liquid. It is most important that the eye should be level with the liquid surface when taking readings.
(B) A burette (C) A pipette
These two are used in chemistry.

(*i*) *For a liquid* a measuring cylinder (very much like an ordinary kitchen measure) can be used. It is not very accurate. See diagram above.

(*ii*) *For a solid with a regular shape* we can calculate the volume by means of a formula (e.g. in the case of a brick, the volume is the product of length $\times$ height $\times$ width).

(*iii*) *For a solid with an irregular shape* we can place it in water contained in a measuring cylinder. The water level rises as the solid pushes its own volume of water out of the way. A solid which floats in water has to be weighted with lead to make it sink. If the solid is large it is put into a displacement vessel full of water (see diagram, page 101). The water which overflows is caught in a measuring cylinder.

Because we usually measure mass in pounds, and volume in cubic feet, density is expressed in lb./cu. ft. Scientists prefer to measure mass in grams, and volume in c.c.s., so then density is in gms./c.c.

TABLE OF SOME APPROXIMATE DENSITIES		
Substance	gms./c.c.	lbs./cu. ft.
GOLD	19·3	1,200
MERCURY	13·6	850
LEAD	11·4	710
IRON	7·9	490
ALUMINIUM	2·7	170
GLASS	2·5	156
SEA WATER	1·03	64·3
FRESH WATER	1·0	62·43
ICE	0·92	57·4
METHYLATED SPIRIT	0·83	52
OAK	0·80	50
PETROL	0·70	43·7
CORK	0·25	16
COOL AIR	0·0012	0·07

1 c.c. of pure water at 4°C .weighs 1 gm. The density of water is then 1 gm./c.c.

We have to specify the temperature because density gets less as the temperature rises. A liquid becomes less dense as it is heated, the warm liquid rises to "float" on top of the denser colder liquid thus producing convection currents (page 61).

SPECIFIC GRAVITY

The term "specific gravity", which sometimes occurs in place of density, is defined as:

the ratio of the weight of a substance to the weight of an equal volume of water.

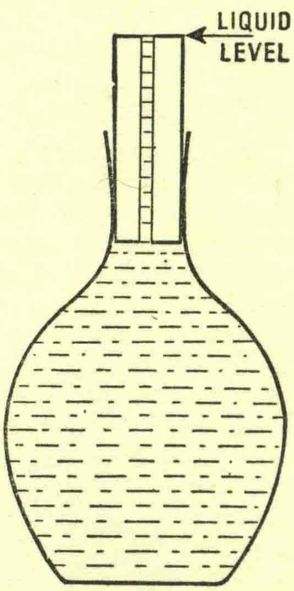
It is numerically equal to density in gm./c.c., but, being a ratio, it has no units. For example, the metal osmium has a remarkably high density of 22·5 gm./c.c., so its specific gravity is 22·5.

THE SPECIFIC GRAVITY BOTTLE

This is a small glass bottle with a well-fitting glass stopper. A fine hole through the stopper allows surplus liquid to escape, thus ensuring that the bottle contains exactly the same volume in every experiment. The outside is carefully dried before weighing.

Example: to find the specific gravity of oil.

weight of empty bottle	= 12.4 gm.
weight full of oil	= 52.8 gm.
weight full of water	= 62.9 gm.
weight of oil	= 40.4 gm.
weight of equal volume of water	= 50.5 gm.
S.G. of oil	$= \frac{40.4}{50.5} = 0.8$



Archimedes' Principle

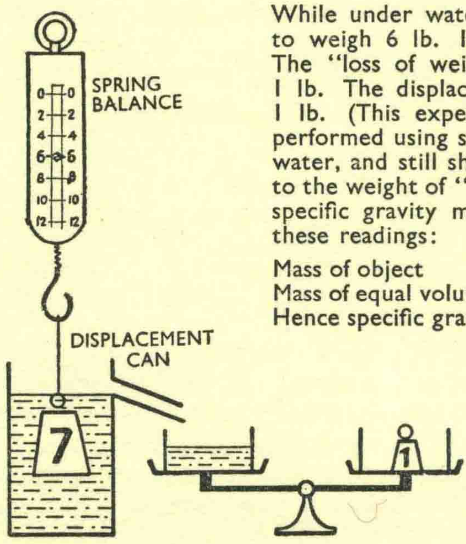
A boy in a swimming bath seems to weigh almost nothing, because he is held up by the water (in fact the bath appears to have gained just the same weight that the boy appears to have lost). This apparent loss of weight is also called upthrust. Even in air we are experiencing a small upthrust. In addition to losing weight the boy in the bath has displaced some of the water, i.e. the water level has risen very slightly. The connection between these two observations was seen by Archimedes over 2,000 years ago. Archimedes' Principle tells us that when a body is weighed in a fluid there is apparently a loss of weight which is equal to the weight of fluid displaced.

This is true whether the body is completely or only partly immersed. A ship apparently weighs nothing while it is afloat; since it has "lost" all its weight, the weight of displaced water must equal the weight of the ship. In general, a floating body displaces its own weight of fluid. The hydrometer (page 99) uses this fact to give a direct means of measuring specific gravity.

A submarine is equipped with ballast-tanks which can be filled with water until the weight of the submarine exceeds the weight of water displaced: under these conditions the submarine sinks. To surface again, water is pumped out of the ballast-tanks.

(Liquids and gases are called *fluids* because they can flow.)

AN EXPERIMENT TO VERIFY ARCHIMEDES' PRINCIPLE



While under water the object appears to weigh 6 lb. In air it weighs 7 lb. The "loss of weight", or upthrust, is 1 lb. The displaced water also weighs 1 lb. (This experiment could also be performed using some liquid other than water, and still show an upthrust equal to the weight of "fluid" displaced.) The specific gravity may be obtained from these readings:

Mass of object	= 7 lb.
Mass of equal volume of water	= 1 lb.
Hence specific gravity	= 7.

Forces that Act in a Fluid

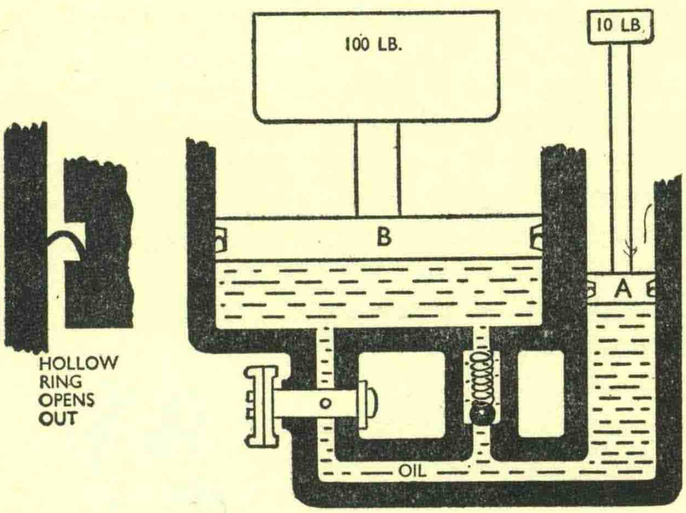
PRESSURE IN LIQUIDS

As a diver descends into the sea, he is subjected to greater and greater pressures. At a depth of 200 ft. he is being squashed by a force of 100 lb. *on every square inch of his body* so it is not surprising that he wears an armoured diving suit. The pressure also depends upon the density of the liquid; if it was possible for the diver to descend into mercury he could only reach a depth of 15 ft. before the pressure exceeded 100 lb. per sq. in.

Pressure in a liquid = depth × density.
It is measured either in pounds per square inch (lb./sq. in.), or in grams per square centimetre (gm./sq. cm.).

Although the weight of a liquid acts vertically downwards, the effect of the weight is transmitted in *all* directions.

THE HYDRAULIC JACK



An effort of 10 lb. is applied to the small piston (A) which exerts a pressure on the oil. This pressure is transmitted to the large piston (B) very efficiently, so there is a force acting on the large piston:

Area of A = 2 sq. in.
Area of B = 20 sq. in.
Pressure on A = force/area = 10/2 = 5 lb./sq. in.
Pressure on B must also equal 5 lb./sq. in.
Force on B = pressure × area
= 5 × 20 = 100 lb.

We seem to be getting something for nothing here since the load is much greater than the effort, but closer inspection shows that the piston B only moves one tenth as far as piston A. The oil is under a considerable pressure and would leak past the pistons if they were not fitted with expanding rings which make a very tight fit in the cylinder as they open out.

PRESSURE IN GASES

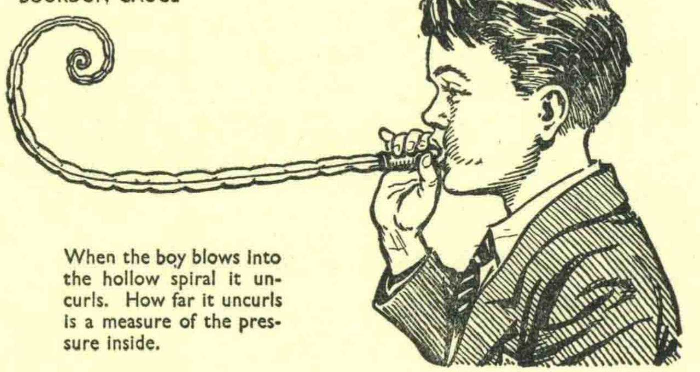
$$\text{Pressure} = \frac{\text{force}}{\text{area}}$$

It acts equally in all directions.

The molecules in a gas are rushing about at high speed. From time to time they collide with the walls of their container and impress a force on it. This force on each sq. in. or sq. cm. is the gas pressure.

It is usually measured by means of a *Bourdon gauge* which works on the same principle as the squeaking toy in the diagram.

TO ILLUSTRATE THE PRINCIPLE OF A BOURDON GAUGE



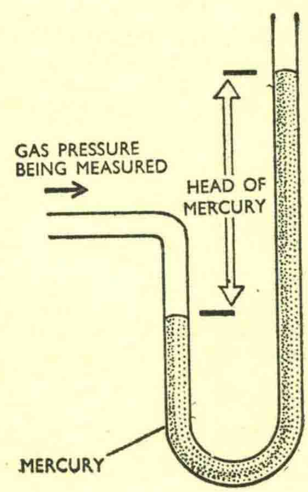
When the boy blows into the hollow spiral it uncurls. How far it uncurls is a measure of the pressure inside.

In a laboratory where greater accuracy is needed, pressure is measured on a *manometer*, a simple U-shaped tube containing a liquid. If large pressures are involved the liquid is mercury because it has a greater density than any other liquid. The pressure is given in "inches" or "centimetres" of mercury but can be converted to lb./sq. in. or gm./sq. cm. by using the formula

Pressure = depth × density.

THE MANOMETER

The pressure on the left exceeds that on the right; liquid has been forced into the open tube to balance the extra pressure. The difference in levels indicates the difference between the applied pressure and the atmospheric pressure in the open tube. The width of the tubes does not matter. To avoid changing manometer readings to lb./sq. in., a pressure is often expressed as a "head of mercury".



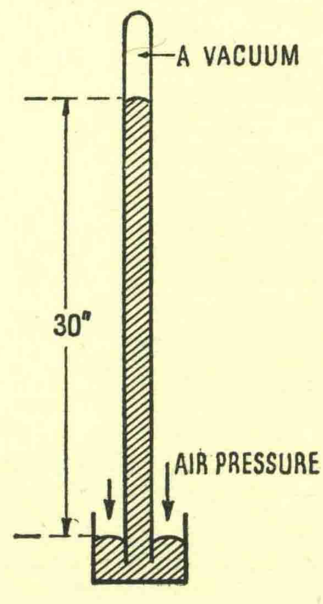
Atmospheric Pressure

The air in our lungs has the same pressure as the air outside, so we do not feel any sense of being "squashed" by the atmosphere. It is difficult for us to realize the enormous pressure which the atmosphere exerts on our bodies. That there is such a pressure may be seen by removing the air from a tin can. A vacuum pump is not necessary for this experiment; the air may be driven out with steam produced by boiling a little water in the can. When the heat is turned off and the can sealed, the steam condenses, leaving a partial vacuum. The internal pressure is no longer equal to that of the atmosphere, consequently the can collapses in a very dramatic manner.

An even more convincing demonstration of the magnitude of atmospheric pressure was given in 1654 by Otto von Guericke. He had invented a pump capable of removing air from a closed vessel. He took two strong, hollow hemispheres 22 in. in diameter with grease around their rims to make an airtight joint. Then, in front of the emperor and an excited crowd, Guericke used his "vacuum pump" to exhaust the air from the sphere, so that the air pressure was acting only on the outside surface, squeezing the two halves together. The climax of the experiment came when a team of horses was harnessed to each of the hemispheres, more and more horses being added, until finally, when each team contained eight horses, the two halves separated.

THE BAROMETER

A mercury barometer may be regarded as a kind of manometer. The closed tube contains no air or other gas so there is no pressure acting above the mercury. The atmosphere is pushing down on the exposed surface of mercury in the bowl, forcing it into the closed tube until the weight of the "head of mercury" exactly balances the weight of the atmosphere.



Gases are Elastic

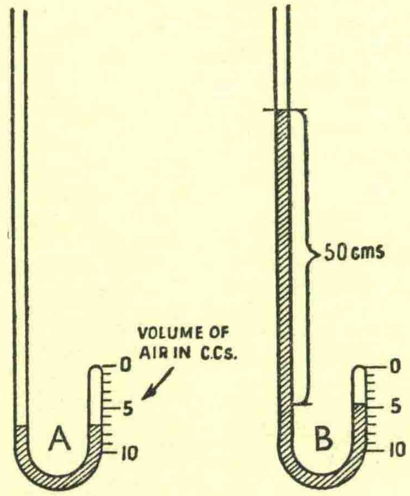
When the volume of a gas is reduced its pressure increases. This may be shown by placing a finger over the end of a bicycle pump. When the plunger is pushed in, the air is compressed into a very small volume and the increase in pressure can easily be felt. Robert Boyle, a founder of the Royal Society, put this observation into words as one of the important laws of physics.

BOYLE'S LAW

The pressure of a fixed mass of gas at constant temperature is inversely proportional to the volume.

This simply means that the product of pressure $\times$ volume of a gas remains the same when it is compressed or expanded.

A SIMPLE EXPERIMENT TO DEMONSTRATE BOYLE'S LAW



Atmospheric pressure = 75 cm. of mercury. (A) levels equal. Pressure P_1 = atmospheric = 75 cm. of mercury. Volume $V_1 = 7$ c.c. $P_1 \times V_1 = 525$. (B) More mercury added. Head of mercury = 50 cm. New pressure $P_2 = 75 + 50 = 125$ cm. New volume $V_2 = 4.2$ c.c. $P_2 \times V_2 = 125 \times 4.2 = 525$. $P_1 \times V_1 = P_2 \times V_2$.

The pressure of the atmosphere is not constant. It changes with the weather (hence its importance to the meteorologist) and it changes with altitude.

The balloon on page 98 is seen to swell out as it rises. This is another illustration of Boyle's Law. Atmospheric pressure decreases with height, so the pressure of gas in the balloon becomes less during its ascent and consequently its volume increases.

The head of mercury in a barometer falls by roughly one inch for every 900 feet above sea level.

The temperature at which water boils depends on the pressure of the air above it. Altitudes have been measured by finding the boiling point of water; it would not be very convenient in an aeroplane!

Glossary

Adiabatic process When a gas expands it absorbs heat; during a compression it gives out heat. Generally heat leaves or enters the gas from the outside to maintain a constant temperature. If no heat is allowed to enter or leave the gas, the expansion or compression is called "adiabatic", there is a change in temperature and Boyle's Law does not hold.

Aneroid barometer (*shown on page* 98) consists of a thin, flexible metal "capsule" from which most of the air has been removed. A spring prevents the capsule from collapsing and there is a continual tug-of-war between this spring and the atmospheric pressure. The in-and-out movement of the capsule is very slight; it is magnified by a system of levers to move the pointer round the dial.

Aspirator pump A simple pump with no moving parts frequently used in chemistry to speed up the process of filtration. Air, or other gas to be pumped, is drawn via a side arm by a jet of water rushing through the pump. Its action may be compared to the suction felt following an express train.

Atmosphere In addition to its usual meaning of the gaseous envelope surrounding the earth, the word is used as a practical unit of pressure. One atmosphere is equal to 14·7 lb. per sq. in., or 76 cm. of mercury.

Barograph An aneroid barometer which records variations in atmospheric pressure directly on a graph. The capsule is connected to a pen, moving it up and down over specially printed paper on a drum rotated by clockwork.

Bernoulli's Principle The pressure of a fluid which is moving depends on the speed of flow. When the speed increases, the pressure decreases and vice versa. The increase in speed can be brought about by narrowing the tube in which the liquid moves. Thus the speeding up of air blown through the jet of a scent spray causes enough reduction in pressure to draw up liquid into the air stream, where it is "atomised".

Blood pressure When measured at the same level as the heart, the blood of a healthy person has a pressure of about 1·4 cm. of mercury. Variation of blood pressure is important in the diagnosis of many diseases. Fortunately it can be measured without direct access to the blood itself. The instrument used (called a sphygmomanometer) consists of a rubber sack wound round the arm and inflated until it stops the circulation. When this happens the air pressure, indicated on a mercury manometer, is equal to the blood pressure.

Buoyancy When any object is placed in a fluid, it appears to lose weight because it is buoyed up by the fluid. The buoyancy of a fluid is this tendency to support objects immersed in it. The buoyant force, or upthrust, is equal to the weight of fluid displaced. (See page 101.)

Capillarity The ability of a liquid to rise up *narrow* tubes. In the case of mercury the effect is reversed, its surface being lower in a narrow tube than in a wide one. Blotting paper soaks up a liquid due to the capillarity of the fibrous mass from which it is made. It is an example of *surface tension*.

Centimetre (*cm.*) One hundredth of a metre. The metre is a standard of length defined by the distance between two marks on a particular bar of platinum. It is equal to 39·37 inches. 1 inch = 2·54 cm. A cube of side 10 cm. has a volume of 1 litre. One litre = 1,000 cu. cm. = 2·12 pts.

Centre of pressure The pressure is greater at the bottom of a liquid than at the surface. An area subjected to pressure by a liquid is thus acted upon by forces of different sizes. The point where the resultant of these forces may be considered to act is called the centre of pressure.

Centrifuge Rotary apparatus for separating solids from liquids. It depends upon the fact that centrifugal force has a greater effect on the substance of greater density (just as the force of gravity, having a greater effect on the denser water, causes it to separate from the less dense oil; see page 97). Blood corpuscles can be isolated from plasma by placing a specimen in a tube and whirling it rapidly: the corpuscles are flung to the end of the tube.

Diffusion Molecules in a fluid are free to move about; if two liquids or two gases are brought together, one will diffuse into the other, mixing completely. E.g., a coloured dye placed at the bottom of a tall vessel of clear water will eventually diffuse through the whole volume of water, giving it a uniform tint. In gases the rate of diffusion is inversely proportional to the square root of the density.

Diving bell A large box without a bottom used in the construction and repair of underwater foundations, etc. It is made of steel to withstand the pressure, water being kept out by compressed air. While returning to the surface the pressure in a diving bell must be reduced slowly to avoid "compression disease" or "diver's bends".

Gram (*gm.*) One thousandth of a kilogram. A kilogram is the mass of a litre of water at 4°C. 1 kilogram = 2·2 lb. 1 oz. = 28·35 gm.

Hydrostatic paradox The apparently impossible situation in which a liquid can exert a force greater than its own weight; e.g., a vessel having a base of area 100 sq. cm. and a height of 10 cm. might hold only 500 gm. of water if it is narrow at the top.
Pressure on base = depth × density =
  10 × 1 = 10 gm. per sq. cm.
Force on base = pressure × area =
  10 × 100 = 1,000 gm.
So 500 gm. of water produces a force of 1,000 gm.!

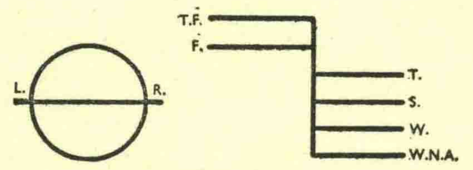
Mass A measure of the amount of matter contained in a substance. Each molecule has a definite "mass" wherever it may be. A molecule taken to another planet would be found to have changed in weight because weight, as we know it, is the attraction that exists between a body and the earth.

Molecule A group of atoms. It is the smallest part of any compound which still shows the properties of the compound. The molecular theory of matter asserts that molecules are a state of motion.

Pascal's Law When pressure is applied to a liquid in a container, the pressure is transmitted equally and undiminished to every part of the container which is in contact with the liquid. It is illustrated by the hydraulic machines.

Pirani gauge A device used for measuring low pressures. The gas whose pressure is to be measured passes through a bulb containing a length of fine tungsten wire. The electrical resistance of the wire varies with the pressure of the gas around it. Change of electrical resistance can be measured very accurately.

Plimsoll line (*load line*) A line painted on the side of a ship to show the limit to which it may be safely loaded. One line is not sufficient because the ship floats higher in salt water than fresh water. The letters L.R. stand for Lloyd's register.



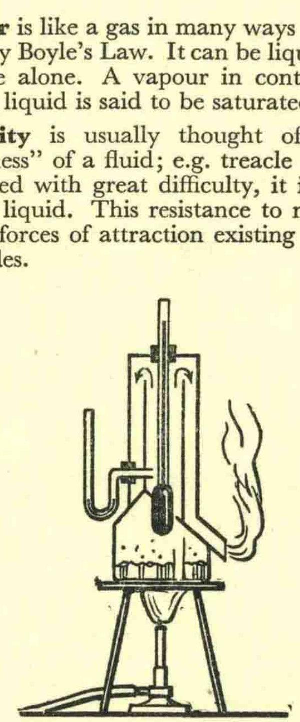
TF = tropical fresh water. F = fresh water. T = tropics. S = summer. W = winter. W.N.A. = winter North Atlantic.

Pneumatics The useful application of the properties of air and other gases. Pneumatic drills and riveters are worked by compressed air. Pneumatic brakes on a train are applied by atmospheric pressure forcing a piston into a partial vacuum.

Surface tension Molecules in the surface of a liquid are attracted inwards. The surface area tends to shrink rather as if the surface were an elastic skin. This explains why a needle can "float" on water and why a drop of liquid is round. It accounts also for the rise of water in capillary tubes. Detergents and soaps reduce surface tension.

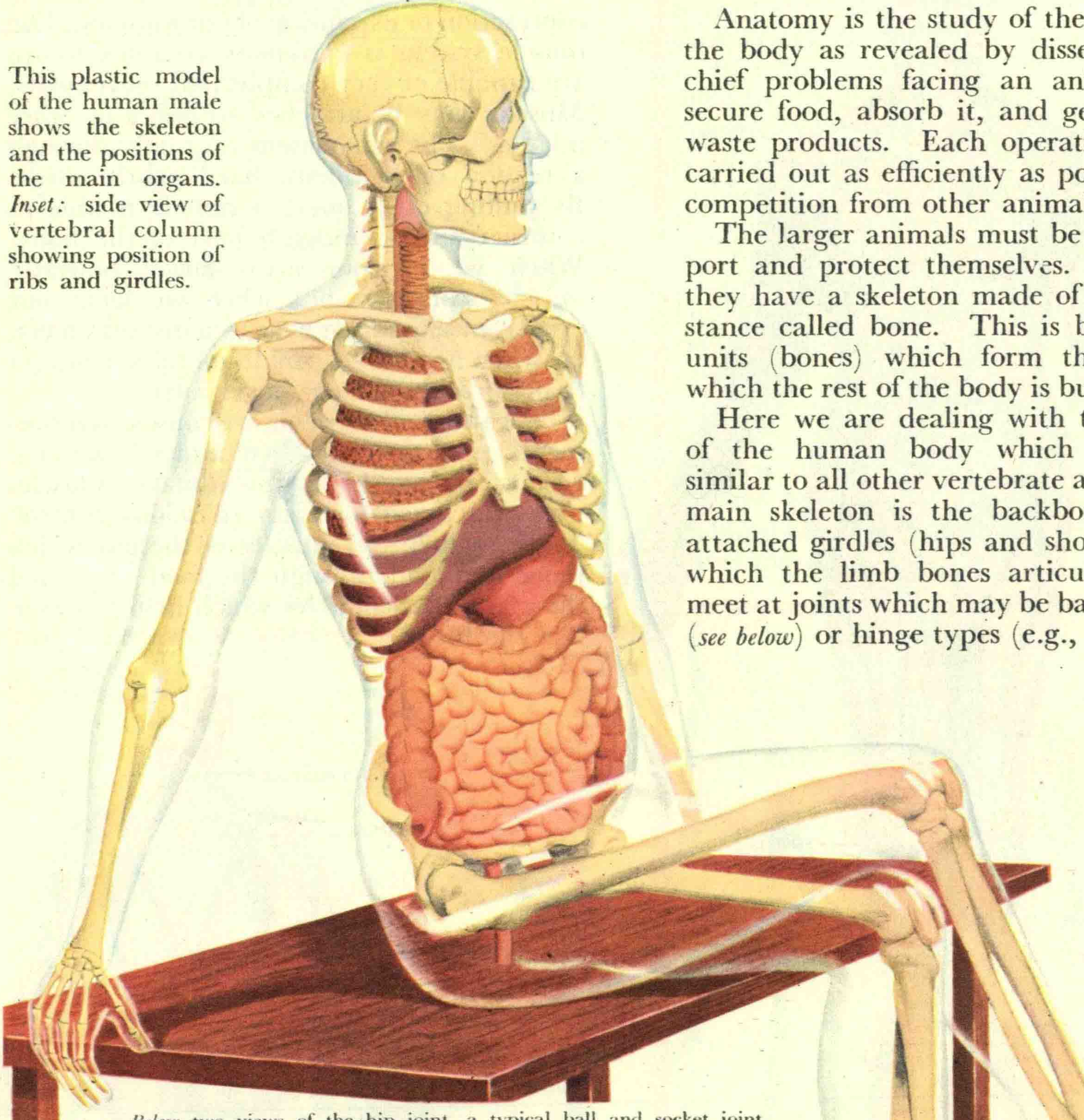
Vapour is like a gas in many ways but does not obey Boyle's Law. It can be liquefied by pressure alone. A vapour in contact with its own liquid is said to be saturated.

Viscosity is usually thought of as the "stickiness" of a fluid; e.g. treacle can only be stirred with great difficulty, it is a very viscous liquid. This resistance to motion is due to forces of attraction existing between molecules.



Hypsometer This is essentially a device for measuring the boiling point of water, but has been used to measure altitudes. Only steam comes into contact with the thermometer so impurities in the water do not upset the readings.

ANATOMY THE STUDY OF HUMAN STRUCTURE



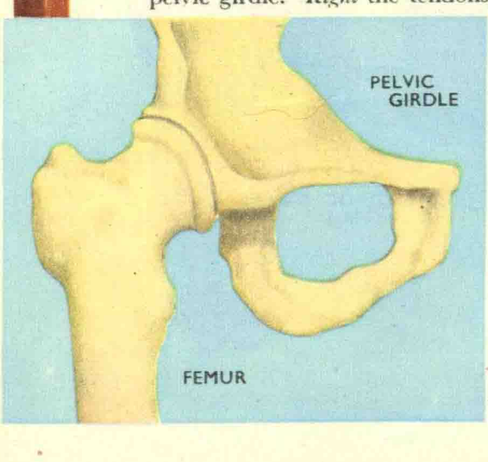
This plastic model of the human male shows the skeleton and the positions of the main organs. *Inset:* side view of vertebral column showing position of ribs and girdles.

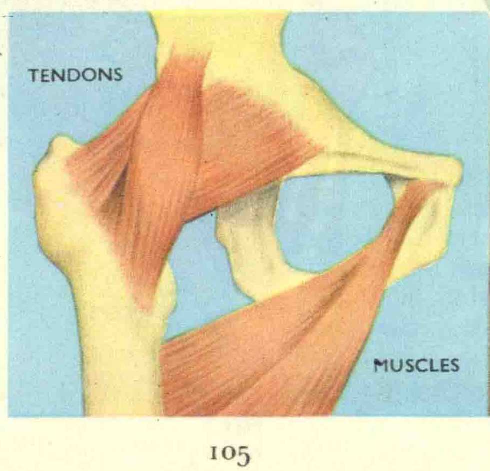
Anatomy is the study of the structure of the body as revealed by dissection. The chief problems facing an animal are to secure food, absorb it, and get rid of the waste products. Each operation must be carried out as efficiently as possible, while competition from other animals is resisted.

The larger animals must be able to support and protect themselves. To do this they have a skeleton made of a hard substance called bone. This is built up into units (bones) which form the frame on which the rest of the body is built.

Here we are dealing with the structure of the human body which is basically similar to all other vertebrate animals. The main skeleton is the backbone, and the attached girdles (hips and shoulders) from which the limb bones articulate. Bones meet at joints which may be ball and socket (*see below*) or hinge types (e.g., knee).

Below two views of the hip joint, a typical ball and socket joint. *Left* the head of the thigh bone (femur) inserted in its socket in the pelvic girdle. *Right* the tendons and muscles.

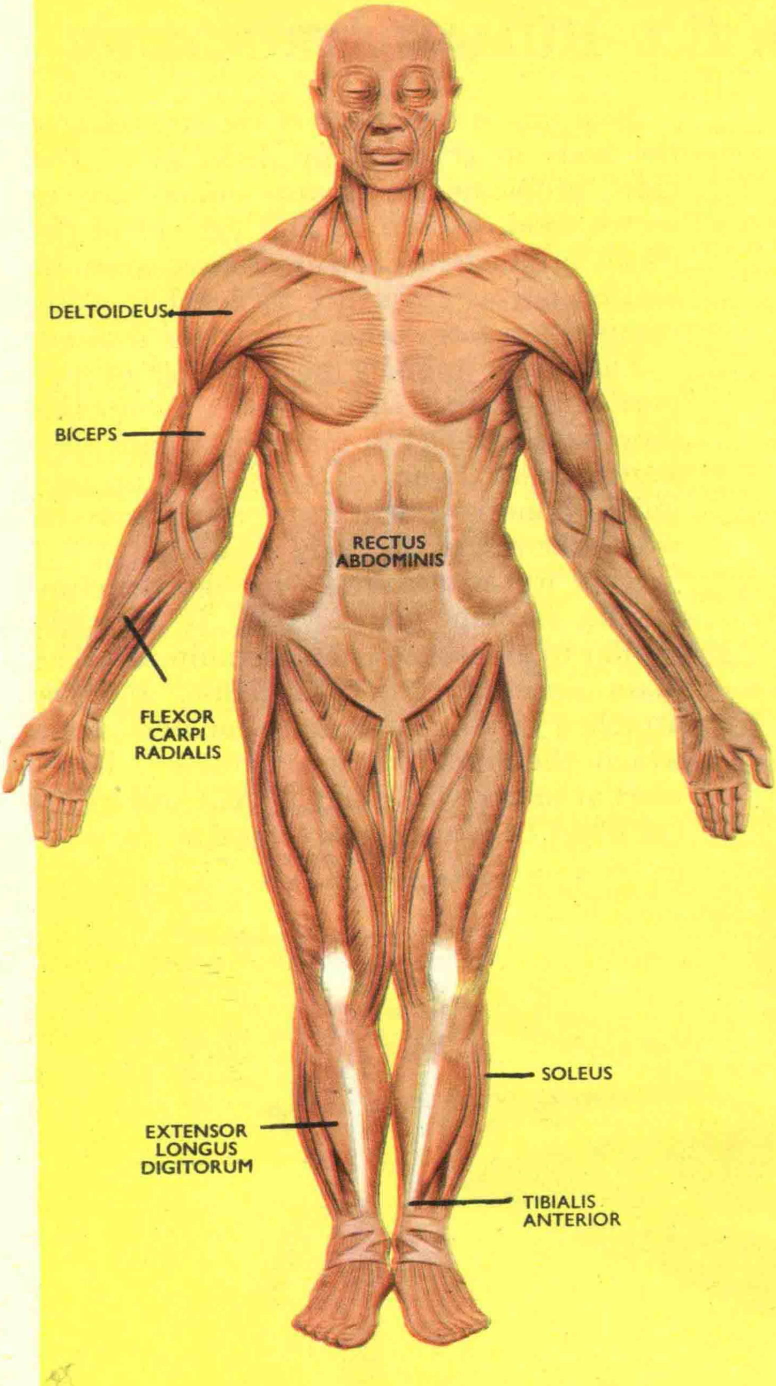


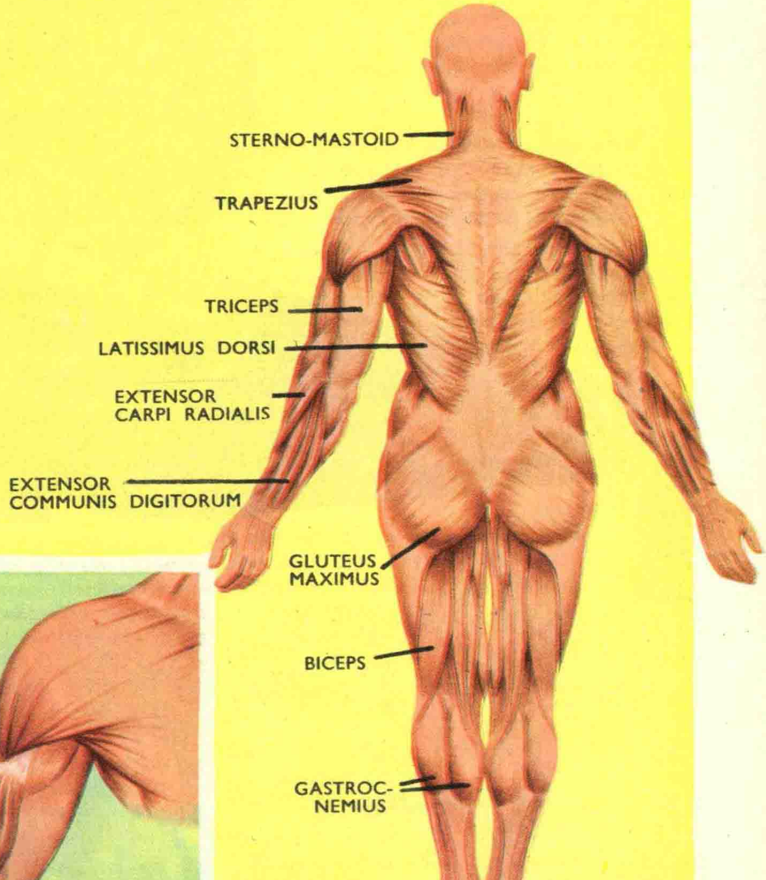


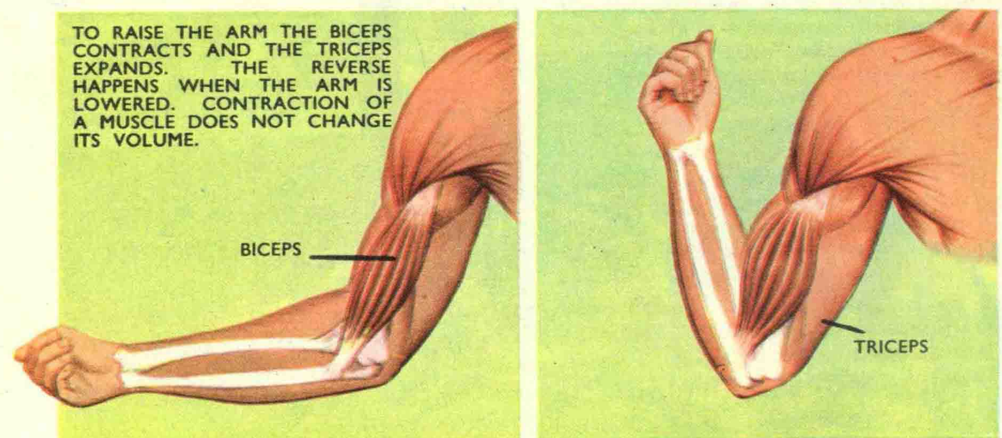
Our Muscles

Every movement we make is due to the contraction or expansion of our muscles. The muscle system is extremely complex so we are capable of very complicated movements. Muscles may be attached to bones or other muscles. The attachment is usually through a tendon or ligament, hard gristly tissue. By pulling on a bone, a muscle is able to contract and so move a part of the body. When we lift our arms large, powerful muscles contract, but when we focus our eyes from something near to a distant object, or when we smile, small muscles contract to perform these finer movements.

The above movements are conscious movements performed by 'voluntary' muscles. In our body we have 'involuntary' muscles over which we have no conscious control. These include the muscles of the gut which move our food through the food tube, and the artery wall muscles which help to circulate the blood.

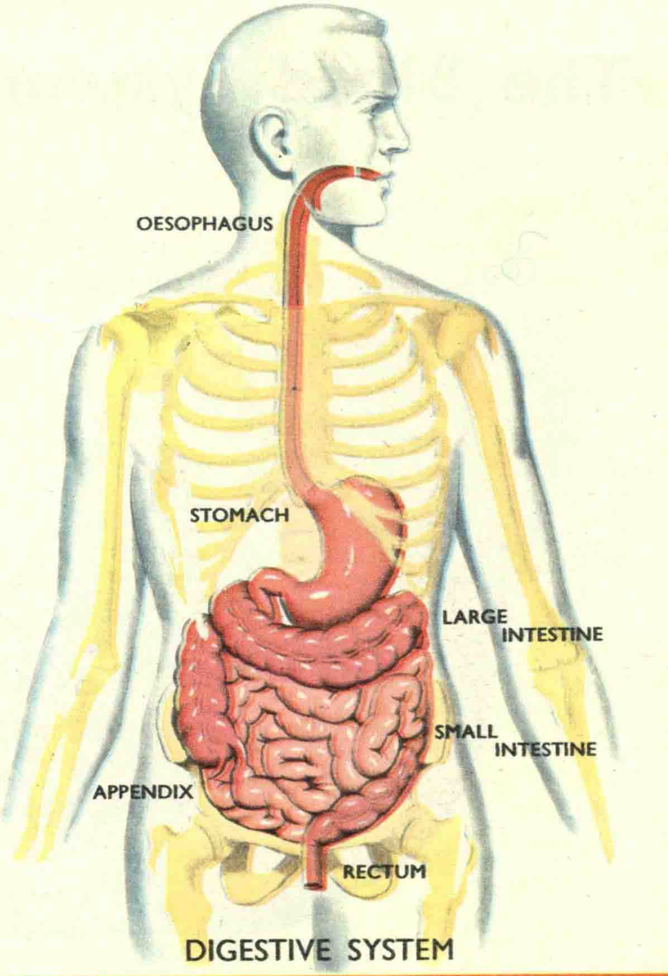






TO RAISE THE ARM THE BICEPS CONTRACTS AND THE TRICEPS EXPANDS. THE REVERSE HAPPENS WHEN THE ARM IS LOWERED. CONTRACTION OF A MUSCLE DOES NOT CHANGE ITS VOLUME.

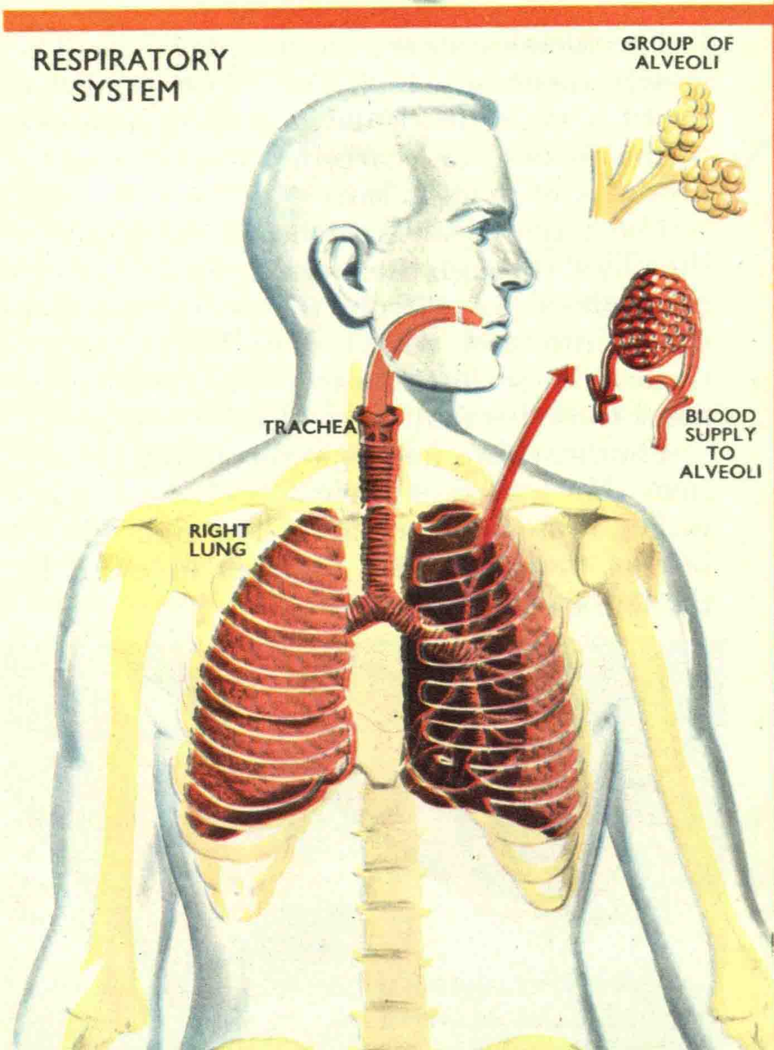
Organ Systems

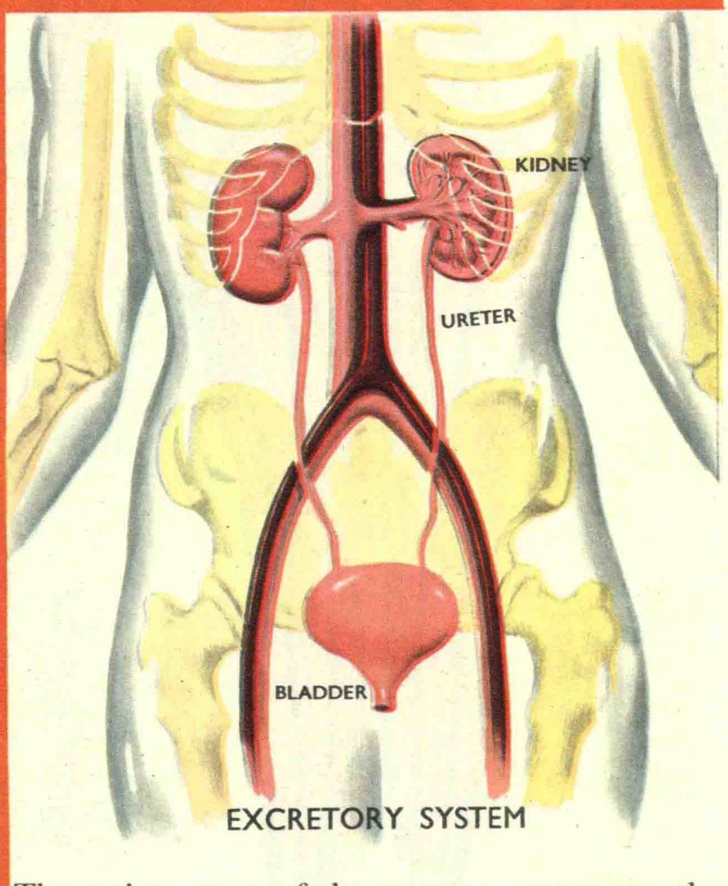


All our body functions are energy-consuming processes. To supply this energy we must have food, in the same way that a railway engine needs coal to produce steam. In fact, the major part of the body cavity is filled by the digestive system. Separating the digestive system from the respiratory system is a tough membrane, the diaphragm.

The oesophagus passes from the throat into the stomach, a large elastic sac capable of contraction. The intestine is made up of a long, thin, small intestine, and a shorter large intestine. Inside it is covered with small projections (villi) so increasing its absorptive capacity.

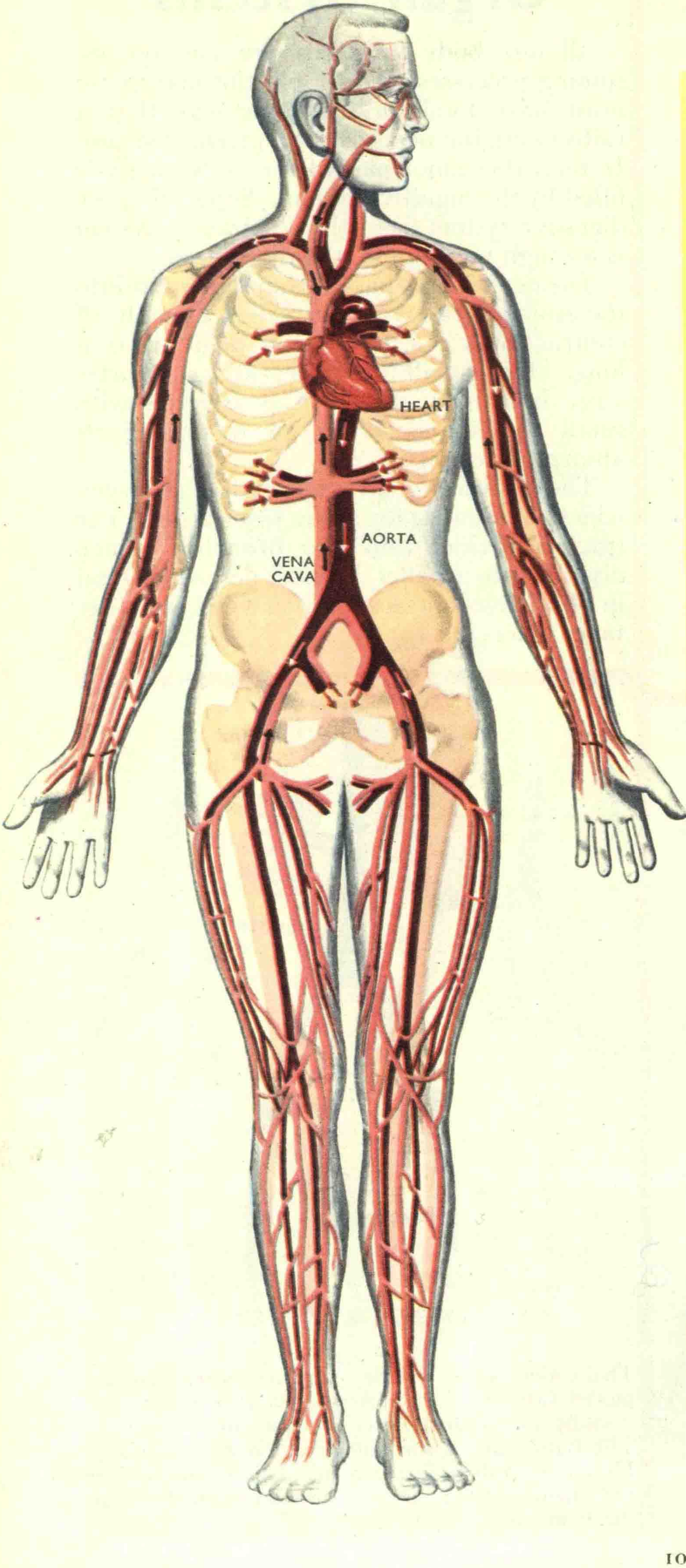
The respiratory system provides the oxygen which is essential for tissue respiration. The trachea divides into two bronchii. Each divides into smaller bronchioles which end in blind alveolar sacs where oxygen exchange takes place.

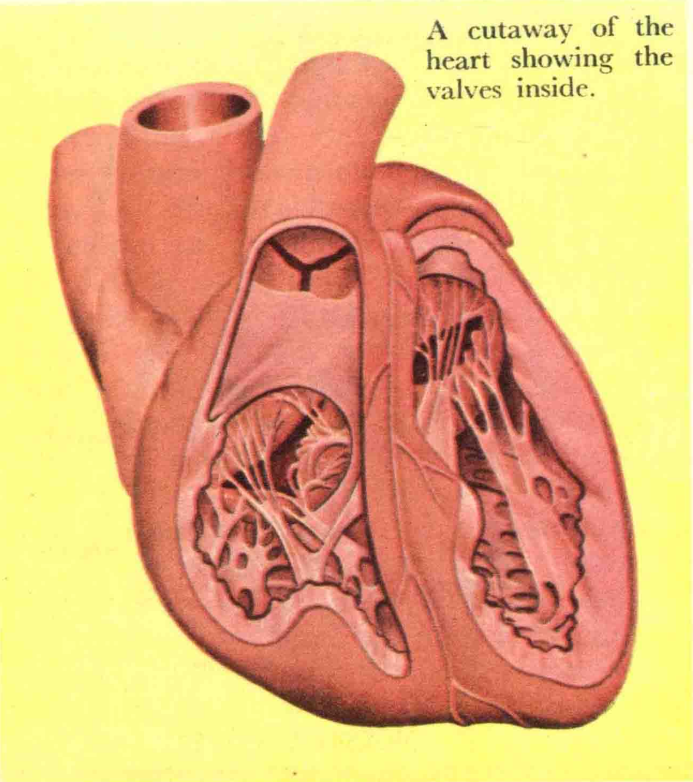




The major organs of the excretory system are the paired kidneys. These are bean-shaped bodies lying dorsally in the body cavity below the diaphragm. The basic unit of the kidney is the kidney tubule. Hundreds of these in the cortex collect impurities in the blood and join to form the ureter which carries the fluid (urine) to the bladder.

The Blood System





A cutaway of the heart showing the valves inside.

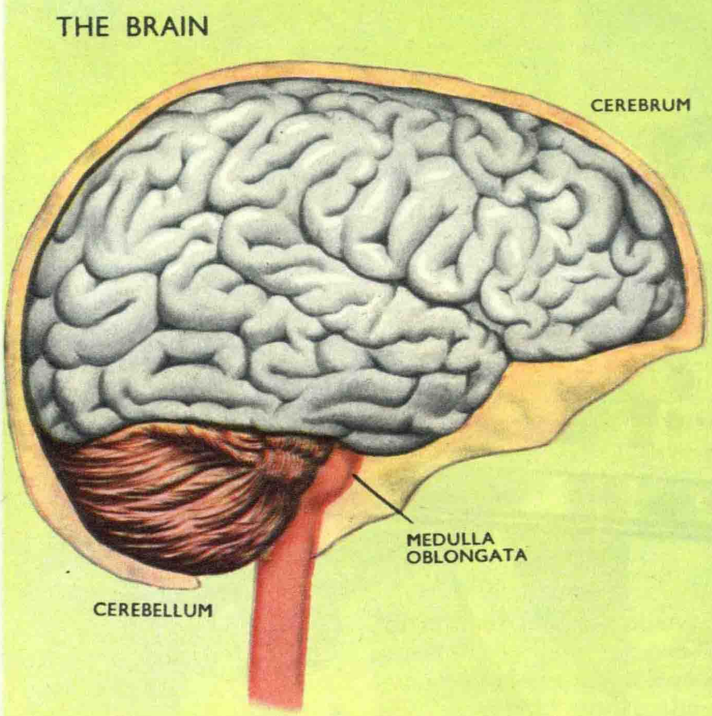
The blood system is a complex system of vessels through which the blood is distributed, passing food, oxygen, and chemicals to the tissues, and carrying away the waste products of metabolism.

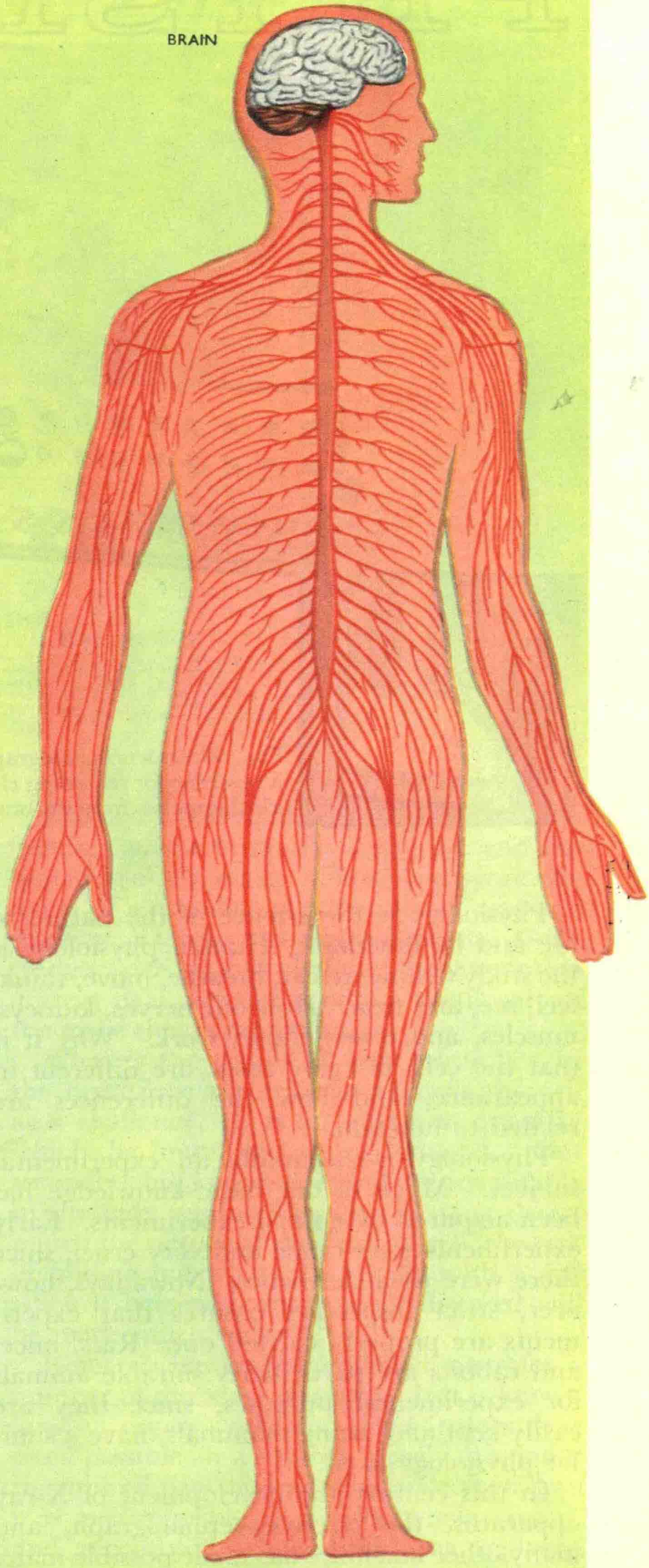
The major organ is the heart which pumps the blood through the blood vessels. Arteries carry blood away from the heart, breaking down into fine vessels (capillaries) in the tissues. These form larger vessels which become the veins that carry blood to the heart.

The heart is a four-chambered organ with two thin-walled auricles, and two thick-walled muscular ventricles. The right chambers of the heart beat together followed by the left side.

Arteries have thick, muscular walls — veins thin walls.

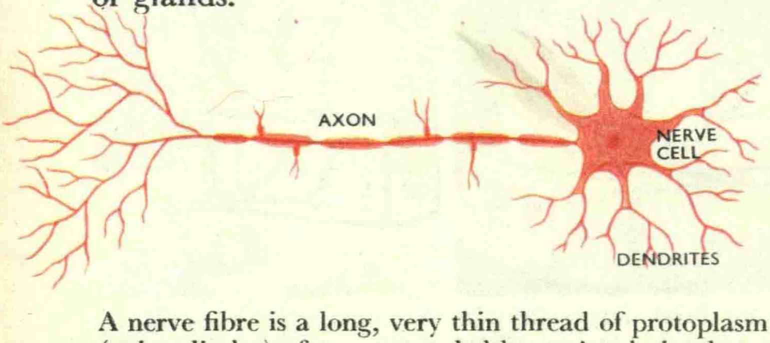
The Nervous System





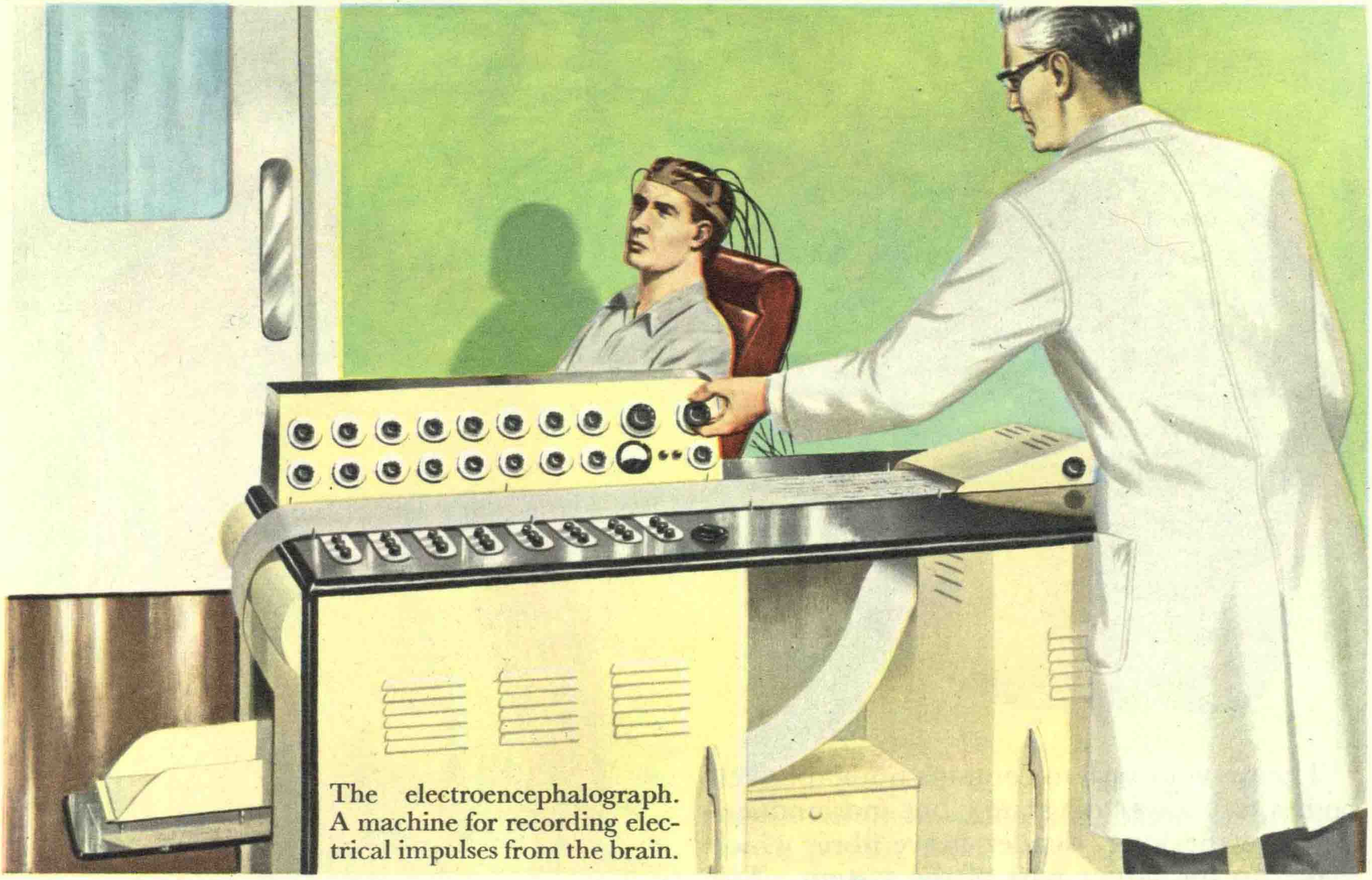
The nervous system contains numerous cell bodies (see lower diagram), but more noticeable are the long, slender nerve fibres which make up the larger part of the system. The fibres are processes of the cell bodies. Neurones are the basic units of the nervous system, each consisting of a cell body and its processes. Most of the cell bodies are situated within the central nervous system i.e. the brain and spinal cord.

The nerve fibres which pass outwards from the cell bodies conduct the nerve impulses. The cell body supplies the fibre with food and maintains it. There are two types of fibre. Sensory fibres send impulses to the brain ; motor fibres carry the reply to muscles or glands.

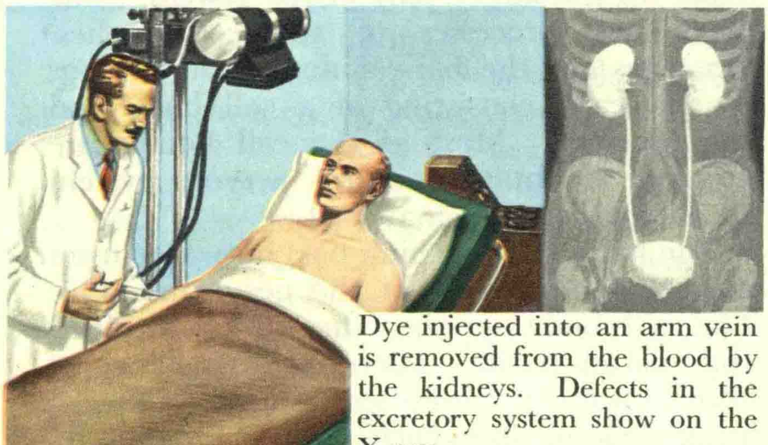


A nerve fibre is a long, very thin thread of protoplasm (axis cylinder) often surrounded by an insulating layer of fat (myelin sheath), and a protective membrane (neurolemma).

PHYSIOLOGY



The electroencephalograph. A machine for recording electrical impulses from the brain.

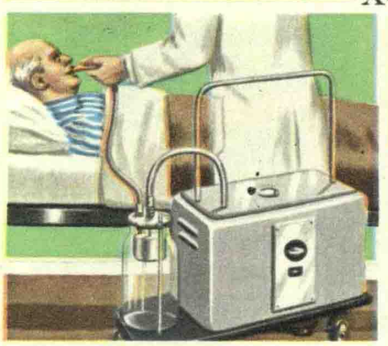


Dye injected into an arm vein is removed from the blood by the kidneys. Defects in the excretory system show on the X-ray.

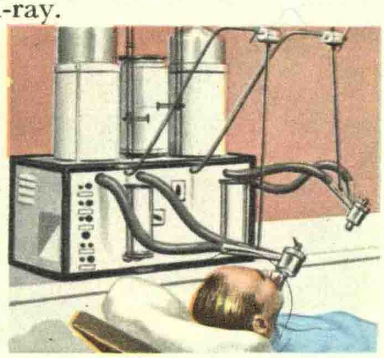
Physiology is the science of the nature of life and its functions. Human physiology is the study of how we eat, breathe, move, think, feel, see, and hear. How our nerves, kidneys, muscles, and other organs work. Why it is that the cells of every tissue are different in appearance, and how the differences are related to function.

Physiology is essentially an experimental subject. Much of our basic knowledge has been acquired by animal experiments. Early experiments were crude and very cruel, since there were no anaesthetics. Nowadays, however, strict inspection ensures that experiments are properly carried out. Rats, mice, and rabbits are particularly suitable animals for experimental purposes, since they are easily kept and, being mammals, have a similar physiology to us.

In this century the development of X-ray apparatus, the electroencephalograph, and many other machines has made possible many more direct observations on the human body.

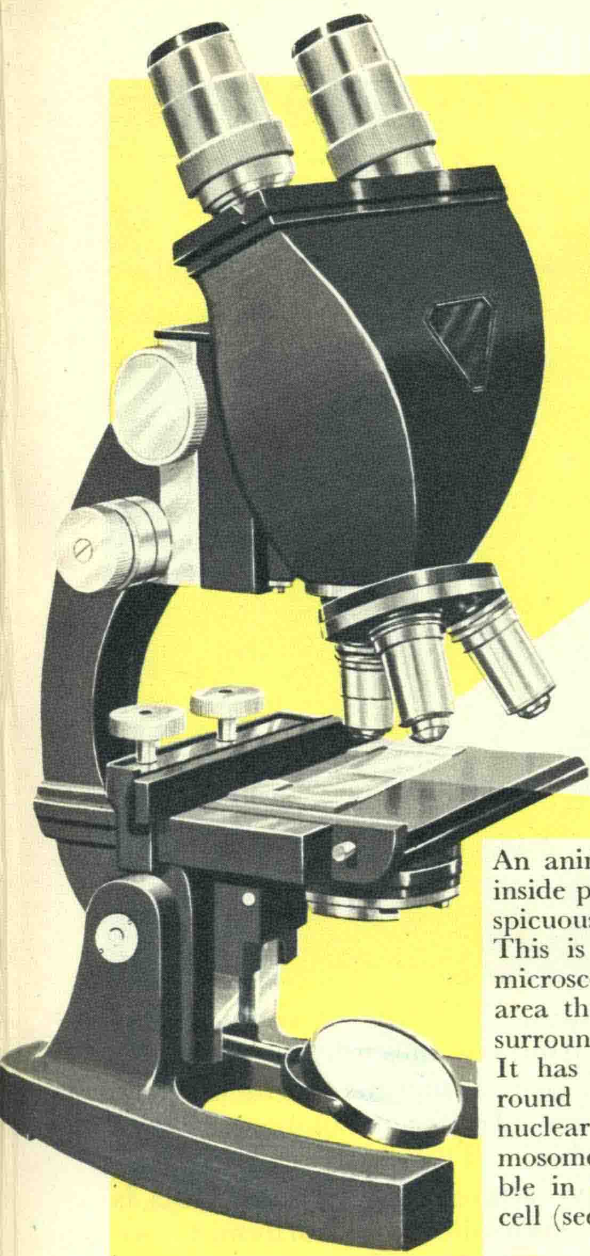


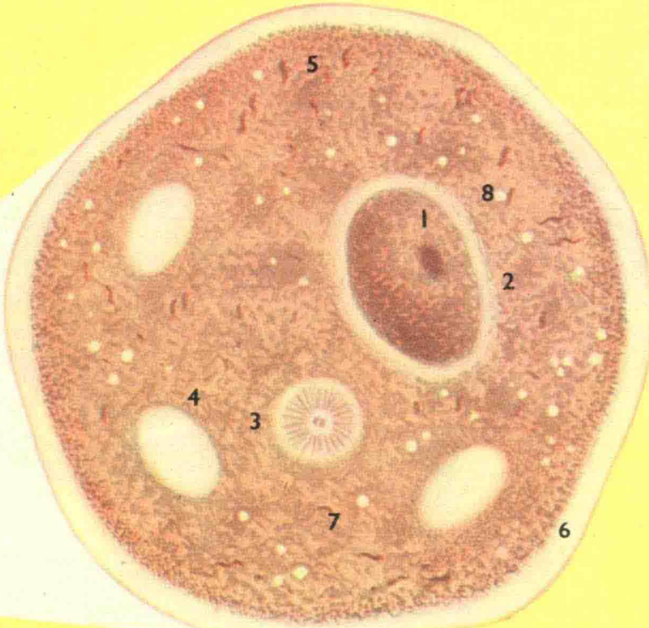
Excess fluid may collect in the stomach. Drawn off by an aspirator it can be checked for germs.



A kymograph records, by means of a tracing, such things as breathing rate and muscle contraction.

Vertebrate Physiology





Key to cell. 1. Nucleus. 2. Nuclear membrane. 3. Centrosome. 4. Vacuole. 5. Mitochondria. 6. Cell membrane. 7. Cytoplasm. 8. Fat globules.

An animal cell has many inside parts, the most conspicuous being the nucleus. This is visible under the microscope as a darker area than the protoplasm surrounding it (cytoplasm). It has a thin membrane round it, enclosing the nuclear sap and the chromosomes not usually visible in the living 'resting' cell (see page 51).

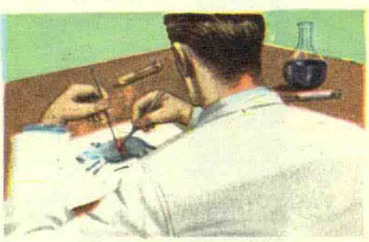
The cell is the smallest living unit able to function on its own. Its structure, and the function of its many minute parts are the quest of a number of present day research workers. The electron microscope and X-ray studies, with other techniques, have revealed a great deal, yet this is only a small part of the maze that is protoplasm.

What is the use of all this research? In the first place the scientist regards the cell as a challenge. It is an unknown quantity which he must get to understand. But secondly, his knowledge will be invaluable in the fight against disease. Having determined the nature of the healthy cell, the task of finding out what goes wrong with a cell when it becomes cancerous or diseased will be made much easier.

Research has so far produced cures for a number of diseases once fatal. If it is known how an organ works and what it does, it is often possible for a surgeon merely to remove the injured part without ill effect. Nowadays it is even possible to replace whole organs, and recently a whole limb was replaced having been severed.

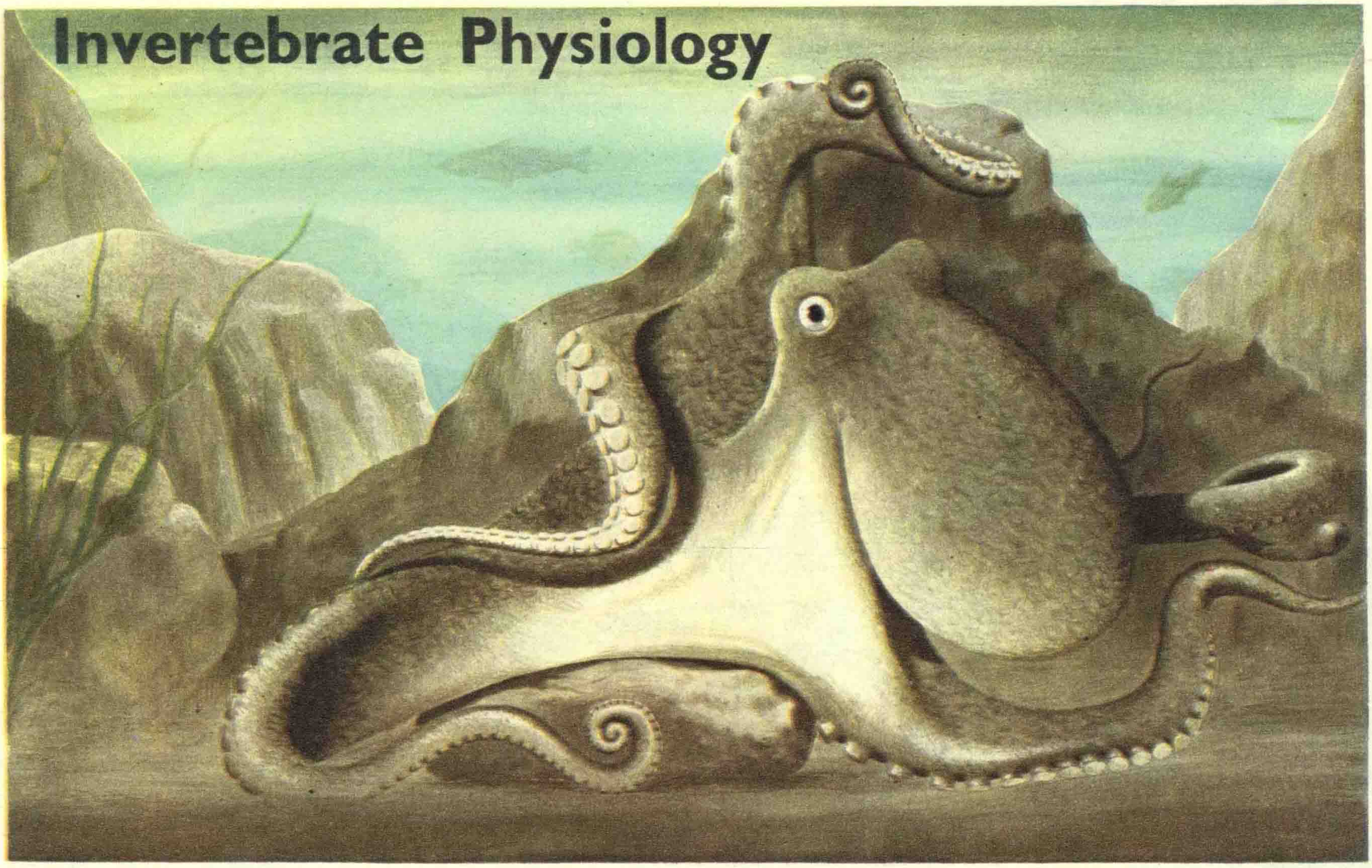
Fluid samples are taken, for example blood going into and blood issuing from the kidney, and analysed chemically. Any differences will help to show what happens in that particular organ.

An organ is removed from an animal. Chemicals given in the correct quantity will keep the animal in a healthy state. By varying the dose, abnormalities will appear. The effects are recorded.



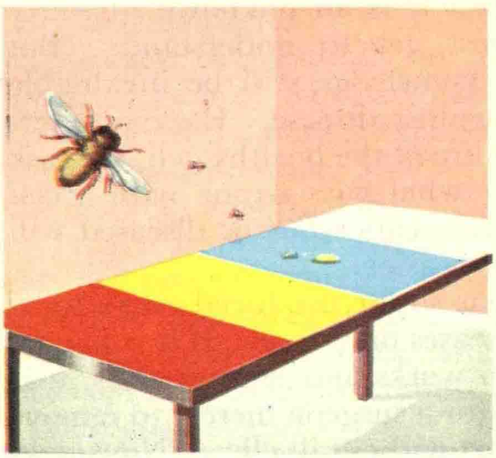
Lack of certain foodstuffs can have grave effects. Animal experiments in which certain materials are omitted from the diet may produce results of use in treating real life diseases.

Invertebrate Physiology

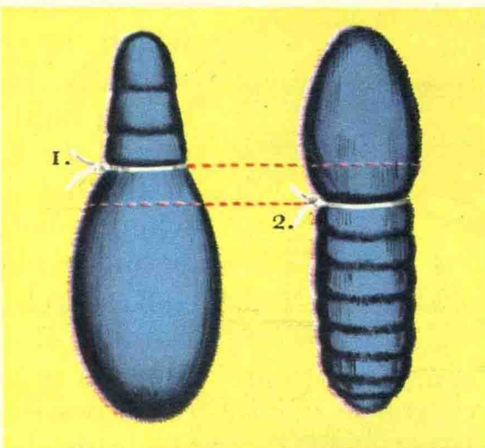


Invertebrate animals comprise some ninety-five per cent of the animal kingdom. Because of their large numbers, and the fact that they are easily obtained, they are particularly suitable for research. There are many similarities in the physiology of vertebrates and invertebrates. Quite often discoveries in the invertebrate field have led to similar vertebrate discoveries.

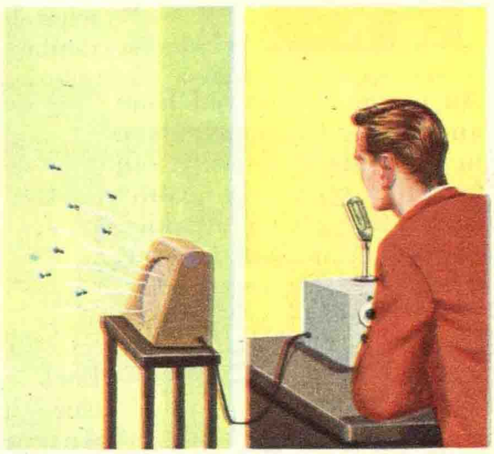
One of the most fascinating things in the animal kingdom is the ability of some animals to regulate their colour so that it blends with their background. This makes them inconspicuous both from enemies and prey. In the octopus there are numerous pigment cells (chromatophores) of different colours scattered through the skin. These can expand and contract to give almost any colour. This is known to be controlled by hormones (see Glossary). Very similar colour changes take place among vertebrate animals, for example some frogs and fish. Nowadays much research is being concentrated on hormone and nerve physiology.



The bee learns to associate a colour with food, and goes to this colour even when the food is removed. This shows it has colour vision.



Above ligature one and below two there is no pupation. A substance (hormone) is released by the brain causing pupation where present.



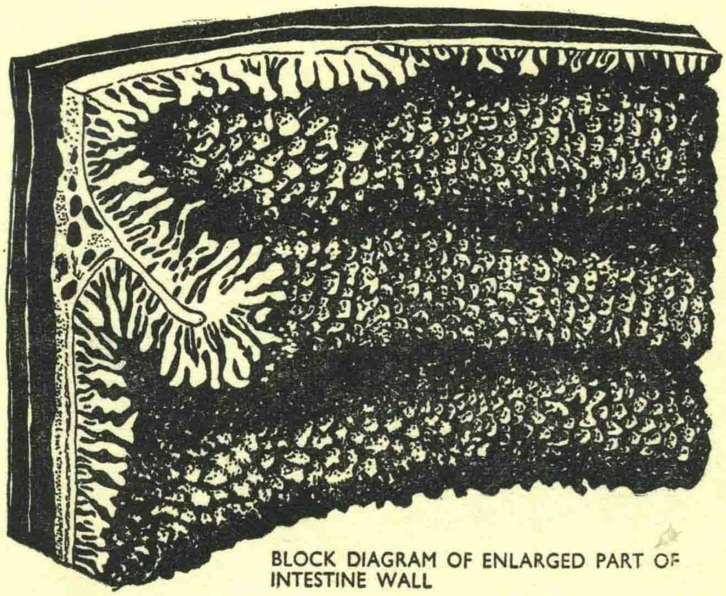
Cricket-like noises are made into the microphone, and attract the crickets to the loud-speaker. This shows that they have hearing organs.

The Fate of our Food

There are three main types of foods: carbohydrates, fats and proteins (see glossary). We also need vitamins which seem to play a vital part in cell respiration, mineral salts, and water. Mineral salts help to maintain the composition of the blood, and water is needed to replace that lost in breathing and excretion.

The table shows the main enzymes that digest the food, where they act, and the work they do. There are, in fact, more enzymes than are included here, and the inter-reactions of enzymes and food are extremely complicated.

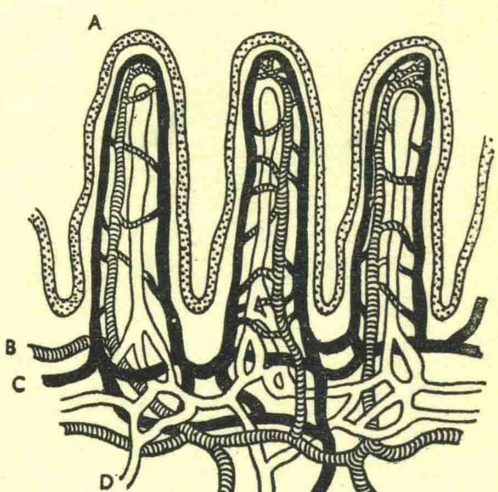
In the small intestine the digested food, now all in liquid form, is absorbed by the blood vessels of the villi. These collect to form the hepatic portal vein which carries the food to the liver.



BLOCK DIAGRAM OF ENLARGED PART OF INTESTINE WALL

On the gut wall ridges are numerous small projections (villi). Each villus has a capillary network in it with an arteriole bringing blood to it, and a venule carrying the blood containing the dissolved protein and carbohydrates away. Fat is absorbed by the lacteals and carried by way of a separate system of tubes to join the blood stream.

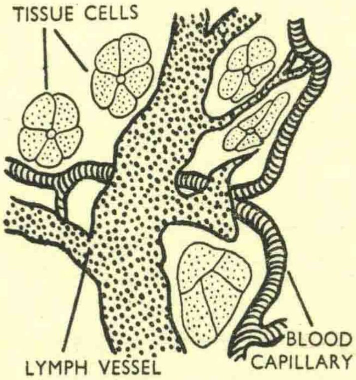
Section through three villi



KEY: A. VILLUS, B. VENULE, C. ARTERIOLE, D. LACTEAL

THE MAIN ENZYMES AND THEIR WORK

Region	*Enzymes*	*Action*
mouth	ptyalin in saliva	starch to sugar
stomach wall	pepsin rennin	proteins to peptones acts on milk protein
duodenum—from liver and pancreas	bile trypsin amylase lipase	turns fat to droplets proteins to amino acids starch to maltose fats to glycerol and fatty acids
small intestine	maltase erepsin	maltose to simple sugars peptones to amino acids



Some of the waste materials in the tissues return to the blood stream only after being carried for a time in a separate system of tubes, the lymph system. The drawing shows a lymph capillary in the tissues. Note its irregular shape.

The blood sugar level is usually fairly constant. If the level in the hepatic portal vein is measured, however, it will be much higher than the level in the rest of the blood stream, as the vessel collects the food from the gut.

The liver is situated in a strategic position in relation to the gut and the blood supply it receives from it. Its major functions are food storage, the building up of simple foods to complex forms, the changing of one food to another (e.g. carbohydrates to proteins), and the conversion of waste material containing nitrogen (e.g. ammonia) to less harmful substances such as urea.

Much of the glucose which the liver receives from the hepatic portal vein is deposited in the liver as glycogen (animal starch), and stored. Any food required by a tissue is passed on from the liver into the blood stream.

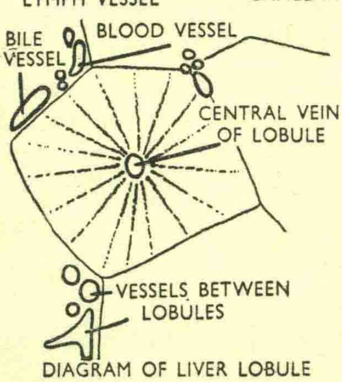
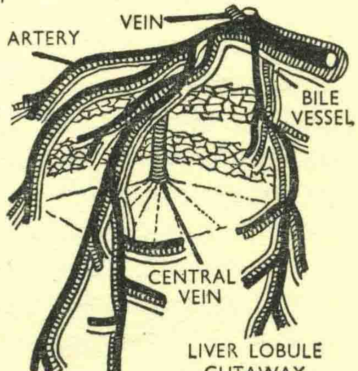
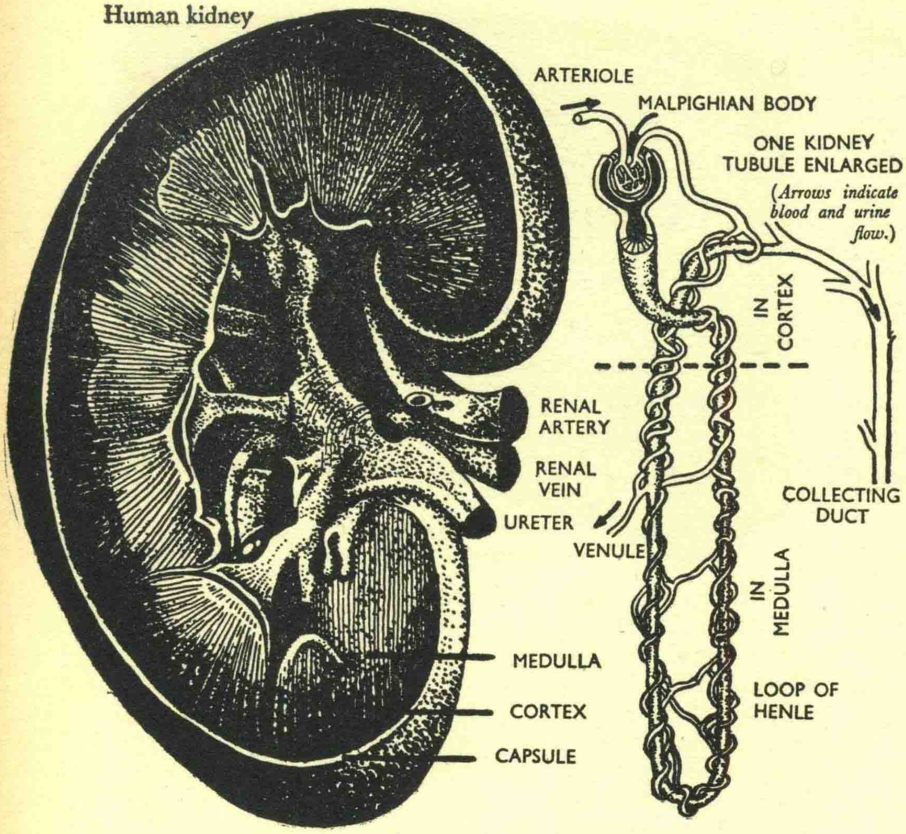


DIAGRAM OF LIVER LOBULE



LIVER LOBULE CUTAWAY

Human kidney



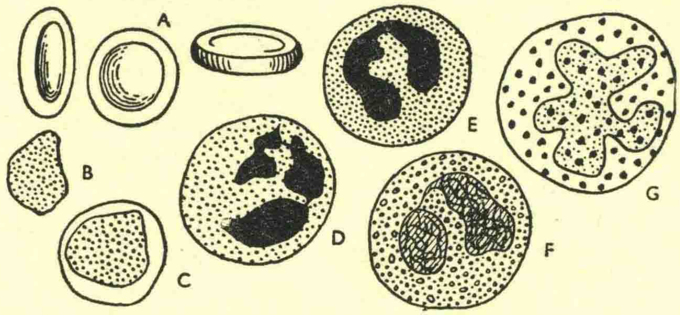
The Kidney

The main functions of the kidney are control of water loss from the body in the urine, and removal of waste nitrogen-containing materials. These two functions are known as osmoregulation and excretion respectively.

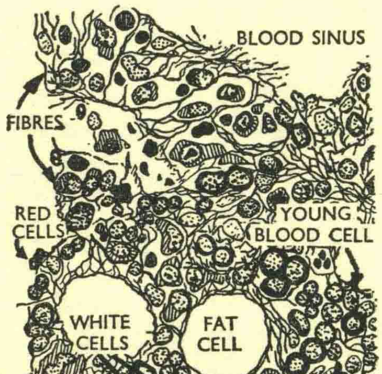
In the cortex (see diagrams, left) are the Malpighian bodies and some parts of the tubules. The medulla contains the bulk of the tubules and collecting ducts. Blood from the renal artery flows into the knot of capillaries (glomerulus) within the Bowman's capsule. Urea, salts and water filter through the capsule wall. Blood vessels round the loops of the tubules re-absorb some water and other substances which are of value to the body, such as glucose, amino acids, vitamins and some inorganic ions. The remaining fluid (urine) passes out of the kidney through the ureter and collects in the bladder.

The Blood—its Structure and Functions

Blood is a fluid tissue. It differs from all other connective tissues in having no fibres in it, and its base is a liquid plasma. In bulk blood appears to be red. The plasma, a straw-coloured solution due to the presence of a pigment carotene, contains about 1 per cent salts, just over 6 per cent proteins, a small amount of glucose, waste substances, and various chemicals such as hormones in very minute quantities. It makes up about 55 per cent of the blood by volume. In the plasma are the blood cells or corpuscles. These are of two main types: red (erythrocytes) and white (leucocytes).



TYPES OF BLOOD CELLS
KEY: A. RED CELLS B. PLATELET C. LYMPHOCYTE D, F, AND G GRANULOCYTES E. MONOCYTE



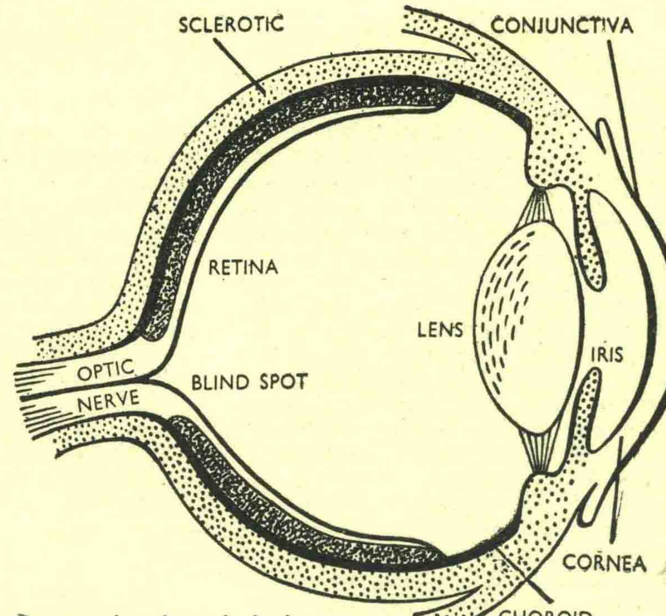
On the left is a diagram of a section through bone marrow. In this tissue are large numbers of white corpuscles which can be released to the blood stream when required. Note that the young blood cells have nuclei. Compare this with the red cells in the diagram above.

The functions of the blood may be grouped under six main headings. These are as follows:

(1) *Distribution of Oxygen*—the pigment hæmoglobin in the blood absorbs oxygen in the lungs. (2) *Removal of Carbon Dioxide*—the result of combustion in the body organs, carbon dioxide is carried in the blood as sodium carbonate. (3) *Distribution of Food*—see page 113. (4) *Removal of Waste Matter*—soluble waste is changed to urea in the liver, and then carried to the kidneys. (5) *Distribution of Hormones*—see glossary. (6) *Distribution of Heat*—blood helps to spread heat throughout the body.

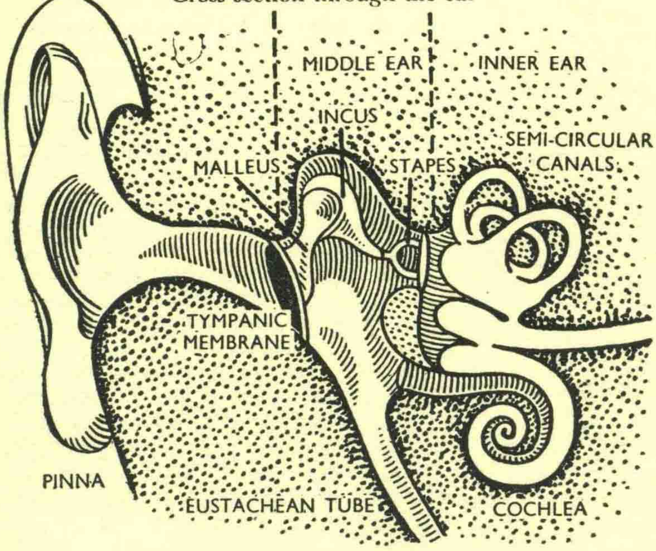
The Eye

The structure of the eye may be compared with that of a camera, and it serves much the same purpose. The outer wall of the eye is called the sclerotic, the front portion of which (the cornea) is transparent. Inside the sclerotic is the choroid, a thin dark membrane. It is perforated at the front and around the hole is a disc, the iris, which gives the eye its colour. Behind the iris is a lens, through which the image is passed and focussed on to the light-sensitive "film" of the retina. The information directed on to the retina is conducted to the brain via the optic nerve. Where the optic nerve enters the eye is the blind spot.



Cross-section through the human eye

Cross-section through the ear

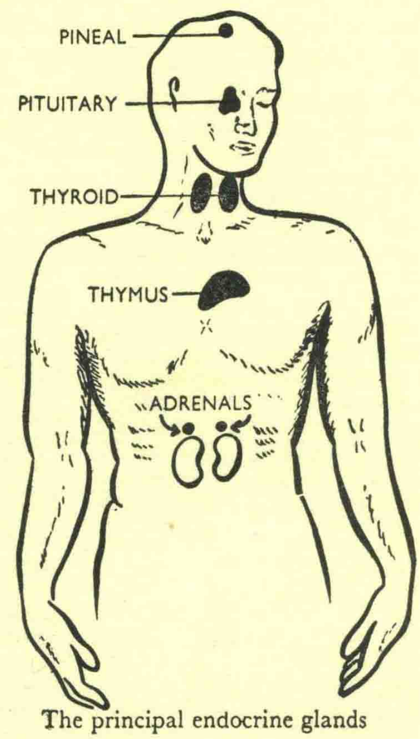


The Ear

The structure of the ear falls into three main parts: the pinna (which we see outside the head), the middle ear (a small air cavity separated from the pinna by a membrane), and the inner ear. Vibrating air (sound) enters the pinna and is directed on to the tympanic membrane, which vibrates in sympathy. The vibrations are conducted across the middle ear by a chain of three small bones. In the inner ear the cochlea, a long spirally-shaped tube, picks up the vibrations which are sent to the brain for translation. The semi-circular canals control balance.

Endocrines—Glands without Ducts

The endocrine glands are organs which produce hormones. The glands are ductless and so the substances they produce are passed into the blood stream and distributed throughout the body. The main endocrine glands and the hormones they produce are as follows: *Thyroid gland*—thyroxine (controlling many internal processes, including tissue respiration), *Thymus gland*—secretion unknown (function doubtful), *Pituitary gland*—phyone, pituitrin and sex hormones (governing growth, involuntary muscles and the sex cycle respectively), *the Adrenals*—adrenalin and cortin (governing amongst other things the physical effects of emotions), and *the Pineal* (whose function is unknown).



The principal endocrine glands

The Study of Heredity

The study of the problems of heredity is called genetics. By heredity we mean the methods by which animals and plants produce others like themselves, though not usually identical. To understand this rather complicated branch of biology it is necessary first to understand what happens when animals or plants of the same species interbreed. The system is basically the same for both. The bodies of both the parents are made up of thousands of cells. Each cell has a nucleus. Inside the nucleus are many pairs of chromosomes (always the same number for any given species), which are so tiny that they can be seen only with a very high-powered microscope. It is on these chromosomes that the factors or characteristics of the species of the plant or animal are carried. We notice, therefore, that rabbits are not born to flowers, or men to earthworms! Even further than this it is apparent that, say, a human child will have certain resemblances to its parents, as well as being of the same species. All the "directions" about the make-up of the child to be born are contained in the chromosomes of the fertilised egg, half of which have been contributed by the father, half by the mother.

The scientific study of heredity really dates back to the work of an Austrian monk, Gregor Mendel (see page 150), who examined the inheritance of the garden pea plant. Briefly, he was concerned at first with one factor in the plant, tallness and its opposite, dwarfness. By constant inbreeding he achieved pure strains of both tall and dwarf peas. Then he proceeded to cross the two varieties. His results may be summarised thus:

Tall × Dwarf

↓

First Generation (F1)

All apparently Tall × All apparently Tall

↓

Second Generation (F2)

1 Tall : 2 apparently Tall : 1 Dwarf

Over the hundreds of experiments Mendel carried out these were the average ratios. By "apparently tall" we mean that these plants looked tall but did not breed true; that is, they were capable of producing either tall or dwarf offspring.

Mendel soon found a formula that would fit the observed facts. Every factor had an opposite factor, and there were always two present in every plant, either two of the same kind or two of opposite kinds. The factor and its opposite could be expressed in similar terms. For example, a pure-bred tall plant would contain TT (T = tall factor), and a pure-bred dwarf plant would contain tt (t = dwarf factor, i.e. the opposite of tall). In these terms the experiment above gives the table

TT × tt

↓

(F1)

Tt × Tt

↓

(F2)

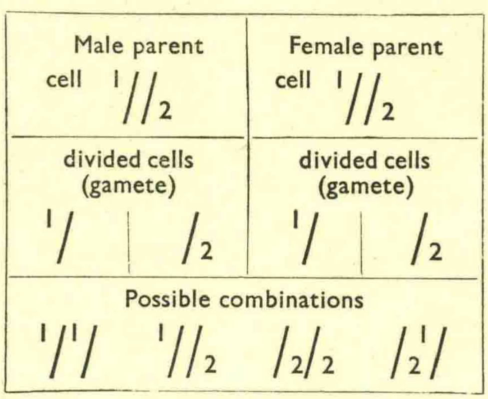
TT Tt Tt tt

This is the ratio we should expect if the factors always combined in ideal proportions.

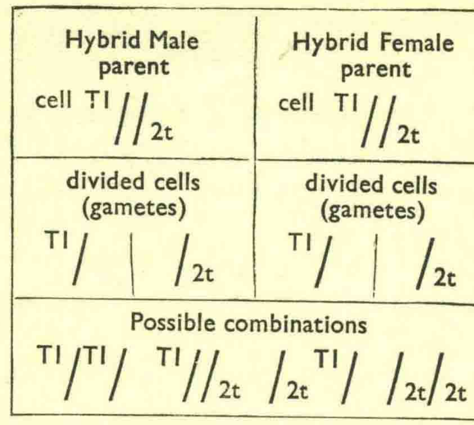
We see now that the apparent talls in fact contain both a tall and a dwarf factor. The reason why they appear tall is that where both factors are present, one (i.e. the tall) is dominant and shows itself, whereas the other is recessive and hidden. It must be noted that the above is something of a simplification, though in general true. (Sometimes when both the factor and its opposite are present they will affect each other and produce a hybrid we can see, as, for example, in the antirrhinum, where red and ivory varieties interbred produce pink as a hybrid form.)

CELL DIVISION AND CHROMOSOMES

We have said that the nucleus of a cell contains several pairs of chromosomes which transmit hereditary factors. How does this fit in with the Mendelian theories described above? Briefly the sequence is this. Before reproduction a cell divides in each parent. In this special type of division the cell splits in half with one chromosome from each pair represented. Assuming that each original cell contained one pair of chromosomes only, the possible results would be as follows (chromosomes are numbered for identification):



Let us assume now that each single chromosome of the male and female parent carries one factor, say tallness (T) or its opposite, shortness (t). We see that a pure tall male will carry a T on each chromosome. A pure short female will carry a t on each chromosome. When the egg (a divided cell with a T) is fertilised (with a sperm containing a t), the result will be a fertilised egg whose nucleus has a pair of chromosomes, one with a T, the other with a t. When the process is repeated with the hybrid cell (Tt) as a parent, the result of cell division will be two divided cells, one with a T on its single chromosome, the other with a t. Assuming that the hybrid mates with another similar to it, the ratio of possibilities in the resulting fertilised egg will be TT : 2Tt: tt; in other words, the ratio seen by Mendel. Perhaps this is seen more clearly when the Mendelian table is incorporated into a chromosome chart:



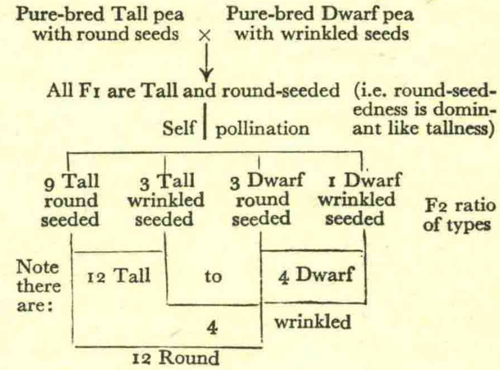
It is on this basis that the study of heredity depends, and all further complications are merely extensions of it.

THE LAWS OF HEREDITY

Mendel's first law of heredity was the *Law of Segregation.* This says that in a hybrid the units for contrasting states of a characteristic (e.g. tallness/dwarfness) separate (segregate) equally as between two different sets of sex cells (e.g. those containing the tallness factor and those containing the dwarfness factor). Since these sex cells combine at random in forming the next generation the contrasting forms of the characteristic are themselves found to separate out amongst the progeny in certain simple ratios. This law has been found to hold for an enormous number of different cross-breedings in a wide range of creatures, both plant and animal.

Mendel went on to state a second law which is now known to be true only under certain conditions. It is, however, a law we must first learn if we are to understand the reasons why it is not always obeyed. It is called the *Law of Independent Segregation* and states that where we study the simultaneous inheritance of two different characteristics, segregation or assortment of one of these proceeds independently of the segregation of the other. We see it in garden peas when differences of height of plant and of kind of seed are transmitted in the same cross.

Two-factor inheritance.



Several facts must be noticed about the four sorts of F2 plant. Consider the segregation of tallness/dwarfness.

There are:

$$\underset{\text{tall plants}}{9 + 3} \quad \text{to} \quad \underset{\text{dwarf plants}}{3 + 1}$$
$$= 12 \text{ to } 4 \text{ or } 3 \text{ to } 1$$

which is what we obtained when making a simple cross of tall × dwarf plants! Similarly for the segregation of round/wrinkled the ratio is also

12 to 4 or 3 to 1 again!

It is obvious therefore that tallness/dwarfness and roundness/wrinkledness have *both* segregated in a normal fashion, and that both have done so quite without affecting each other (i.e. *independently*).

It is easy to see in this cross that the F1 individuals, whilst only displaying the dominant characteristics of tallness and round-seededness, must be of constitution Tt:Rr (where R = round-seed factor and r = wrinkled), because they are the product of unlike but pure-bred parents. What, however, happens when plants of this sort form ovules and pollen? Well, we have seen for tallness/dwarfness that sex cells will be produced in such a way that

50% contain T
and
50% contain t.

It will also happen for round/wrinkled seededness that sex cells must be produced so that

50% contain R
and
50% contain r.

Now we have seen from the breeding results that each of these segregations proceeds independently of the other. *Therefore,* since a factor for height and factor for seededness must both be in each sex cell, half of the T-containing sex cells must also contain R and the other half r. Likewise for the t-containing ones, half will also contain R and the other half r. So *there will be four sorts of gametes*, those containing TR, Tr, tR, tr; and *each kind will occur equally abundantly.* Since this must be as true for ovules as for pollen, we can find out the probable combinations in producing the next generation (F2) by a device similar to that used to work out the fixtures between the teams of a football league. It is called the chessboard method.

Chessboard shows all possible unions between — Four equally abundant types of pollen grain (columns); Four equally abundant types of ovule (rows)

	TR	Tr	tR	tr
TR	TT RR Tall Round	TT Rr Tall Round	Tt RR Tall Round	Tt Rr Tall Round
Tr	TT Rr Tall Round	TT rr Tall wrinkled	Tt Rr Tall Round	Tt rr Tall wrinkled
tR	Tt RR Tall Round	Tt Rr Tall Round	tt RR dwarf Round	tt Rr dwarf Round
tr	Tt Rr Tall Round	Tt rr Tall wrinkled	tt Rr dwarf Round	tt rr dwarf wrinkled

A little totting up will show that the final result for large numbers of matings will approach the ratio

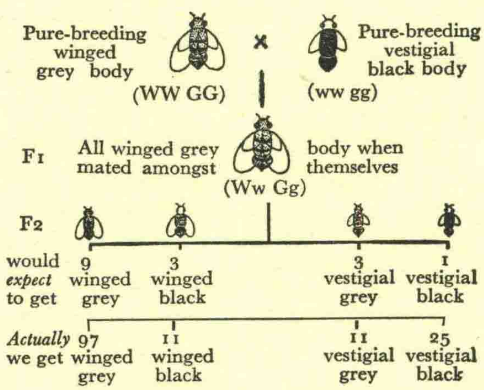
9	:	3	:	3	:	1
tall round		tall wrinkled		dwarf round		dwarf wrinkled

We must further notice that the chessboard shows that of the 9 tall round only one ninth are pure breeding (i.e. TT RR); and of both the tall wrinkled and the dwarf round only one third are pure breeding. These last two types are novelties—not having appeared in these crossings before—and by selection they can be secured in the pure breeding forms TTrr and ttRR. This shows how hybridisation can occasionally produce new types or varieties which are at once "fixed", as the saying goes (that is, are true breeding when mated with others of their own sort). You will also notice that all the pure-breeding types lie on the diagonal of the chessboard. This is where each team in the football league meets itself!

A similar example for the animal world is Drosophila, a tiny fly that lives on ripening fruit. In the wild state it is a winged fly with striped body. In cultivation states of near winglessness (vestigial) and of black (ebony) body are known. These are due to recessive factors (or genes).

LINKED CHARACTERISTICS

We have said that Mendel's Law of Independent Segregation is not always obeyed. Here is an example. In Drosophila black body (gg) is the result of the action of a *different* recessive gene to the ebony one that was crossed previously. It is alternative to *grey* body (GG). Let us make the cross shown here:



It can be seen that in this cross

$$\text{winged/vestigial} \left(\frac{97 + 11}{11 + 25} = \frac{108}{36} = \frac{3}{1}\right)$$

$$\text{and grey/black body} \left(\frac{97 + 11}{11 + 25} = \frac{3}{1}\right)$$

are segregating as expected from Mendel's First Law, but since the ratio of 9:3:3:1 is not obtained they are obviously not segregating independently. You will notice that the types that occur too frequently are winged, grey body and vestigial, black body. Do you notice that these are the associations which existed in the grandparents (F1)? Somehow winged and grey body have stuck together in later generations more often than they have gone apart. This is also the case for vestigial and black body. Such behaviour is called linkage But note that this linkage is *sometimes* broken (i.e. it is partial), otherwise we would in the F2 get no flies showing winged, black body or vestigial grey. These two sorts are called the "cross-over" types because in them the original linkage has been broken. All very puzzling? Well, yes and no! If we suppose that the sex cells from the F1 that carry the cross-over combination of genes are only formed in the ratio of 1:5 (instead of 1:1) to those carrying the linked combination then we shall get a chessboard like this:

Types and proportions of sex cells formed by F1 (columns; 1 Wg and 1 wG: Cross-over type sex cells); rows 1 Wg and 1 wG: Cross over type of sex cell

	5 WG	1 Wg	1 wG	5 wg
5 WG	25 WW GG winged grey	5 WW Gg winged grey	5 Ww GG winged grey	25 Ww Gg winged grey
1 Wg	5 WW Gg winged grey	1 WW gg winged black	1 Ww Gg winged grey	5 Ww gg winged black
1 wG	5 Ww GG winged grey	1 Ww Gg winged grey	1 ww GG vestigial grey	5 ww Gg vestigial grey
5 wg	25 Ww Gg winged grey	5 Ww gg winged black	5 ww Gg vestigial grey	25 ww gg vestigial black

By random mating of the sex cells we would get:

Winged grey	25 + 5 + 5 + 25 + 5 + 1 + 5 + 1 + 25 = 97
Winged black	1 + 5 + 5 = 11
Vestigial grey	1 + 5 + 5 = 11
Vestigial black	25 = 25

This is the ratio that was obtained in the experiment.

The exact proportion of cross-over sex cells can easily be spotted by crossing an F1 female with a pure-breeding male that has both the recessive characteristics. Thus:

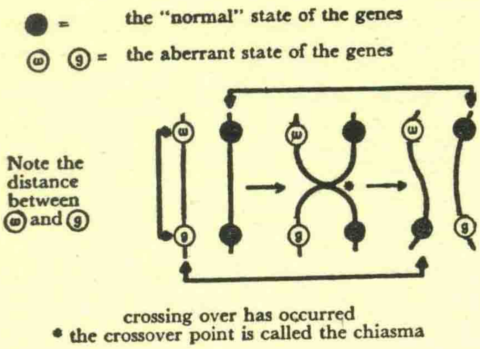
F1 hybrid winged grey female (Ww Gg)	×	Pure-breeding vestigial black male (ww gg)

The pure-breeding fly can *only* produce sex cells containing w and g. The hybrid will produce the usual four types, thus:

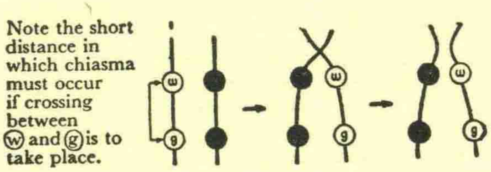
Ratio of sex cell types from F1 hybrid	Sex cells from pure-bred male all wg	Actual ratio in F2	Ratio if segregation had been independent
5 WG	5 Ww Gg winged grey	5	1
1 Wg	1 Ww gg winged black	1	1
1 wG	1 ww Gg vestigial grey	1	1
5 wg	5 ww gg vestigial black	5	1

Thus, this being a simpler cross than the interbreeding of the F2, the ratio for the cross-over to non-cross-over sex cells is seen to be the same as the ratio between the four kinds of progeny.

It now remains to find the mechanical basis for this behaviour. If linkage between two traits were absolute we could suppose that the genes controlling them were situated in the same chromosome. But how can this explain a partial linkage such as we have discovered? The answer comes from the observation by cytologists of chromosomes when they are dividing in a reducing division. The chromosomes that make up any pair can then be seen to wrap themselves round each other in a spiral. Whilst in this state they break across their length



Crossing over between w and g is more likely to occur if their relationship is as above than if it is as below.



In this instance although a chiasma has formed there will be no crossing over between w and g i.e. they are still in the same chromosome.

and exchange portions. It is this exchange of substance that keeps them held together. When they separate, because of this segment interchange, they are not quite the same chromosomes that commenced to pair. The point of breaking and interchange is called the chiasma. *If* it occurs between the positions of the linked genes we happen to be studying, these will be divorced from one another, and cross-over sex cells will be the result. If the interchange does not occur between the genes in question then cross-over sex cells will not be produced. It is evident that crossing-over will in general be least likely to occur if the genes in question are close together in the chromosome, and most likely if they are far apart in the chromosome. In fact the percentages of cross-overs in matings of this kind have been used to calculate the distance of particular genes from one end of the chromosome in which they are carried and their distance apart. The percentage is termed the cross-over value which is used to draw chromosome maps to show gene positions. On the opposite page there is a chromosome map made by this method.

It happens that in the glands of Drosophila which produce its saliva (or spit) the chromosomes are extra large in size and their construction can very clearly be seen under the microscope. Extremely careful examination of these chromosomes in differing varieties of the fruit fly has made possible identification in the chromosomes of the sites for the genes of characteristics already identified by breeding. In the figure, lines join the gene sites in the chromosome to the gene positions as calculated on the cross-over map. That is the extent to which many traits can be linked up to the make-up of a creature's chromosomes!

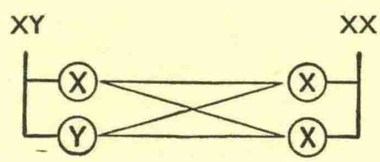
SEX INHERITANCE

This provides another straightforward example of segregation—but this time of chromosomes rather than of particular genes. In the fly Drosophila, as in man and the mammals generally, the cells of males show a chromosome shortage. Male Drosophila have the fourth pair of chromosomes unequal in size, a smaller one X and a larger one Y. On the other hand the cells of females have the fourth pair made up of two similar X-type chromosomes.

When a female Drosophila forms eggs by a reduction division all her eggs must contain an X chromosome—i.e., $XX \rightarrow X + X$. Not so with males. Half their sperm cells will contain an X chromosome and the remaining half a Y chromosome—i.e.,

$$XY \rightarrow X + Y.$$

The cross male Drosophila × female Drosophila is therefore like the back cross of Mendel's hybrid pea with the recessive parent.



The result is:

$$\underbrace{XX\ XX}_{\text{2 females}} \qquad \underbrace{XY\ XY}_{\text{2 males}}$$

or a ratio of 1:1 between the sexes.

It is now clear why in populations of animals the sexes normally remain more or less equal in numbers. Once again we have a correspondence between a ratio obtained in breeding tests and a visible difference in the chromosome make-up of the individual produced. It will be seen that in cases of this sort it is the sperm from the male parent which determines the sex of the next generation.

THE INFLUENCE OF ENVIRONMENT

When a creature starts life as a result of the union of egg and sperm, its heredity, received at random from each of its parents, is no more than a collection of possibilities. These have to be worked out (or frustrated) in the course of growth or development. At fertilisation the creature is not male or female, though (as we have seen) it *is* potentially male or potentially female. Likewise for the other inherited differences. Accidents may happen in the course of growing up, and deviation from the appointed path may occur, heredity notwithstanding.

The extent to which environment, or nurture, can influence heredity varies from case to case. We can do little by feeding, exercise or thought to change our eye colour, though slight changes may accompany ill-health. On the other hand, much can be done from without to change hair colour, if its inherited character is unacceptable! Heredity is at work in both cases. In one of them it is more readily modified by outside influence than in the other. An extreme case is the fish Fundulus whose young can be made to develop only one eye by carefully altering the salt balance of their water during the early stages of growth. A control group reared under normal con. ditions develops the usual pair of eyes. A similar experiment can produce one-eyed frog tadpoles from eggs of normal heredity for two eyes.

Without heredity there can be no beginning, without environment there can be no development! Thus we see that the mature individual is not the product of heredity *v.* environment but of heredity + environment.

HEREDITY IN MAN

Wherever his heredity can be studied by observing the transmission of an abnormal state of some particular characteristic, as Mendel did for peas, the laws of heredity seem to apply to man just as they do to plants and other animals. But there are many difficulties in the study of human heredity. Man's families are usually small ones, so the test of large numbers has to be made by means of statistical adjustments. His generations are long ones, as he rarely produces children before the age of 14 years, and the family may not be completed until late in life. So the study of man's heredity can advance only slowly. Again, memories are short; few of us know anything definite enough about our grandparents for the human geneticist to rely very much upon past generations as test material for his theories. Lastly, many of the things about man that interest us most—his disposition, his health, his intelligence, his good or bad looks—are complex characteristics difficult to measure and, where hereditary influences have been discovered at work, they have frequently proved to be very complicated in their mode of action.

But the picture for man is not without outline, nor indeed without highlights! As in Drosophila, so in man—males and females consistently differ in their chromosomes. Women have 48 chromosomes (= 2 × 23 + a sex pair XX), whilst men have $47\frac{1}{2}$ chromosomes (= 2 × 23 + a sex pair XY, the Y chromosome being tiny). Boys and girls are born in nearly equal numbers due to the segregation of X and Y chromosomes into equal numbers of sperm.

Blue eye colour in man is *recessive* to other eye colours. Thus blue-eyed children can in a small proportion of cases be born to two dark-eyed parents. This is where *both* parents happen to be hybrid for their dark eye colour and each carries a recessive gene for blue. In such instances about 1 in 4 of their children may have blue eyes.

Those human traits like height, skin, colour and intelligence that are present in varying degrees of intensity (we are not *either* tall *or* short, brilliant *or* dull!) can be considered as due to the existence of inheritance systems in which many pairs of genes act in such a way that their effects add up.

Experimental evidence for this type of inheritance mechanism in man is hard to get, though it exists for some differences of skin colour. For rats an hereditary system of this sort seems to control whatever "intelligence" is measured by skill in solving mazes in the search for food. In the study of human conditions such as height, and whatever "intelligence" is measured by intelligence testing, we have to rely on the less satisfactory method of testing by means of statistical analysis, whence comes some of the controversy about whether these characteristics in man are chiefly the result of good heredity or of good environment.

Glossary

Absorption of food The process by which the digested food passes through the gut wall into the vessels of the villi. Fat passes into the lacteals while the protein and carbohydrate materials pass into the venules which collect to form the hepatic portal vein which goes to the liver.

Adrenaline is a hormone produced by the central area (medulla) of the adrenal gland. It is important in conditions of stress, controlling the distribution of the blood in the body, relaxing the muscles of the lung tubes, causing the liver to release sugars into the blood, and increases the production of red blood cells (erythrocytes) by the spleen. It is an important drug in the medical world. One use is for the relief of asthma.

Adrenals Paired endocrine glands situated at the head end (anterior) of the kidneys. They each have two main regions, an inner medulla and an outer shell, the cortex. The medulla produces adrenaline (see above). The cortex produces a whole range of substances and is essential for life. Its removal, in man, leads to Addison's disease, which is fatal. The substances produced by the cortex affect the kidneys, the quantity of food materials in the tissues and the blood, and the sex glands. Cortisone, which is produced by the cortex, is used for the relief of rheumatism and many other diseases.

Amino acids Chemicals always containing carbon, hydrogen, oxygen, nitrogen and sometimes sulphur. Most are breakdown products of proteins. Some amino acids are formed during the digestion of the proteins in food. There are approximately twenty-five known amino acids.

Assimilation is the passing of food materials from the bloodstream into the tissues either to provide energy for general activities or for growth and repair.

Autonomic nervous system A system of nerves which controls the internal parts of the body and works in conjunction with the central nervous system. For example, stimuli from the autonomic nerves affect the muscles of the blood vessels and the gut.

Bile A green watery fluid containing no enzymes which adds water to the food and contains salts (bile salts) which affect fat in the food so that it is more easily digested by the fat enzymes (lipases).

Blind spot The part of the eye where the optic nerve leaves the retina. Here there are no light-sensitive cells so that an image received there is not transmitted to the brain.

Blood clotting or coagulation This is valuable to the individual when he is cut or wounded. If clotting did not take place he would die through loss of too much blood. By a complicated series of chemical actions fibres are formed in the blood and these trap the blood cells, so plugging the cut or the wound. Internal cuts or haemorrhages can result in a clot blocking a blood vessel or being carried to the brain, which may have serious consequences. People lacking the ability to clot their blood are termed haemophiliacs.

Blood groups It was found that during blood transfusions the receiver of blood often died due to the clotting or agglutination of his blood. This was due to the fact that many people have different types of blood. Only blood of particular types will mix without clotting due to the presence of substances within the blood. There are four main blood groups termed O, A, B, and AB, though these are subdivided into about seventy types. During a blood transfusion care must be taken to see that a patient receives blood of his own group.

Bowman's capsule The cup-like end of a kidney tubule within which is the glomerulus or knot of capillaries which together are called the Malpighian body (see page 114).

Buccal cavity The cavity into which the mouth opens (in vertebrates). It houses the tongue and teeth in most vertebrates.

Capillaries Very fine blood vessels which have a thin wall only one cell thick. Chemicals and gases in solution pass both ways between the capillaries and the tissues via the lymph vessels (see page 113).

Carbohydrates Compounds containing carbon, hydrogen and oxygen. Usually the hydrogen and oxygen ratio is the same as that in water, i.e. 2H:1O. It is thought that carbohydrates occur in all living tissue. They are important sources of energy and are the basic food source of animals. Examples are glucose (the sugar in blood) and glycogen (the main food storage material in the liver).

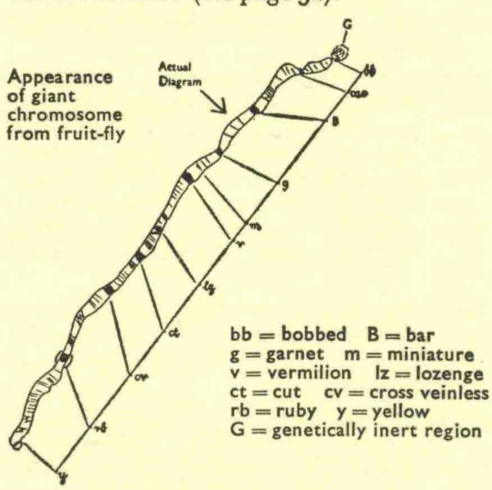
Carnivore An animal which eats only meat.

Cell division (see page 53, Mitosis and Meiosis).

Cerebellum A part of the brain (see page 109). In man it is primarily concerned with the control of movement and posture. For example, it ensures that we stand on two legs.

Cerebrum In man the largest part of the brain and the controlling centre of nearly every body activity. It is rather like a computer in that it stores and sorts the information that it receives.

Chromosomes (see page 52).



A map of gene positions as explained on page 118.

Crossing over A term used in genetics to describe a phase in meiosis (see page 53) when chromosomes lie alongside each other and appear to exchange parts by crossing over each other. In fact there is no physical cross-over.

Deamination The process by which excess protein in the food is converted in the liver to urea, a relatively harmless substance which is excreted by the kidneys, and other substances.

Diaphragm A muscular wall which divides the body cavity into two parts, the thoracic cavity which contains the lungs and the abdominal cavity containing the stomach and intestines. During breathing in, the diaphragm becomes flattened, so enlarging the thoracic cavity. The pressure inside falls so that air passes into the lungs. The reverse happens during breathing out.

Digestion The process by which the food taken into the body is broken down by enzymes into materials which can be absorbed through the gut wall. The enzymes and their actions are tabled on page 113.

Dominant character If the offspring of a black and white animal were black, then black is said to be the dominant character.

Drug Substance used to cure, relieve or prevent disease, either by internal or external administration. Examples include hormones, vaccines and many plant derivatives including antibiotics.

Endocrine organs Glands which produce substances (hormones) that are released directly into the blood vessels supplying them and not into a duct. For this reason they are sometimes known as ductless glands. Examples are the pituitary, thyroid, and adrenals.

Enzymes Complex protein substances made by living cells which act as catalysts. That is, they are able to alter the speed at which chemical reactions take place without being permanently changed themselves. Examples are the digestive enzymes (see page 113).

Erythrocyte The scientific term for a red blood cell (see page 114).

Excretion The removal of waste materials from the body fluids, mainly by the kidneys which collect urine (mostly waste nitrogen materials). The removal of carbon dioxide from the lungs when we breathe out is also a form of excretion, as is sweating and the growth of hair and nails.

Fats Complex compounds always containing carbon, hydrogen and oxygen which are esters (organic salts) of glycerol ($CH_2OH.CHOH.CH_2OH$) formed by the combination of glycerol and fatty acids (e.g. stearic acid $CH_3\ (CH_2)_{16}COOH$). Fats often occur as storage material in animals and play an important part in the structure of nerves and membranes.

Gene (see page 53).

Genetics (see page 53).

Glands Organs that produce and release fluids. They may have ducts (e.g. salivary glands) or release the fluid directly into the bloodstream (endocrine glands). The liver is both an exocrine (ducted) gland and an endocrine gland.

Glomerulus (see Bowman's capsule).

Glycerol In the human body it is a breakdown product of fats during the digestive process. It passes easily through the intestine wall and into the lacteals (see also Fats).

Glycogen Sometimes called animal starch, it is a carbohydrate storage material found in the liver and muscles. It plays an important part in cell respiration, its breakdown providing energy for such things as muscle contraction.

Haemoglobin is a purply-red pigment contained in the red blood cells (erythrocytes) of the blood. In the lungs the blood comes in contact with the inhaled oxygen. This combines with haemoglobin forming bright-red oxyhaemoglobin. In this stage it is carried to the tissues, where, because the fluids are slightly acid, the oxygen is released to the tissues and haemoglobin is re-formed. The reddish colour of haemoglobin is due to the presence of iron in the haemoglobin molecule.

Hair Found only in mammals rooted in the deeper layer of the skin (dermis). Each hair has at its base a thimble-like wedge of cells, the papilla, containing blood vessels which bring food, and which is surrounded by the root of the hair. The shaft of the hair is set in a hollow tube, the hair follicle. Sebaceous glands open into the hair follicle, producing oil which keeps the hair flexible.

Herbivore An animal which eats only vegetable material.

Histology The study of the minute structure of tissues.

Homoitherm An animal which can keep a fairly constant body temperature. Man has a normal temperature of 98.4°F.

Hormone Substance produced by an endocrine gland which is carried by the bloodstream to another part of the body, where it acts.

Hybrid The offspring of two organisms which are genetically different, i.e. in their gene make-up.

Insulin. A hormone produced by a special type of tissue (Islets of Langerhans) in the pancreas. It is very important in the control of carbohydrates in the body, helping to regulate the blood sugar level among other functions. Lack of insulin results in the disease diabetes mellitus. Excessive amounts of sugar circulate in the blood and are excreted in the urine. Diabetes is treated by injection of specially prepared solutions of insulin.

Kidneys Paired body organs which clear the blood of waste materials, to form urine (see page 114).

Leucocytes The white blood corpuscles (see page 114).

Linked genes Genes present on the same chromosomes.

Liver The largest gland in the body, it has a variety of functions. These include regulating the amount of food materials released to the bloodstream, storing glycogen and fat, breaking down excess protein (deamination), producing bile, protection of the body from harmful substances (toxins), the storage of iron and copper, the making of vitamin A and regulating the composition of the blood.

Malpighian bodies (see page 114).

Metabolism The sum total of the chemical processes taking place in an organism.

Mitochondria Small spheres or thread-like bodies found in the cytoplasm of cells (see page 111). They carry "packets" of enzymes which control the metabolism of a cell. They are particularly linked with cell respiration.

Mutation (see page 53).

Natural selection One of the reasons which Darwin and Wallace advanced in their joint essay on the theory of evolution. Briefly they inferred that the animals and plants best suited to their environments were the ones that survived. In this way improved animal and plant types evolved.

Nucleus (see page 111).

Omnivore An animal which eats any kind of food, meat or vegetable.

Ovary The organ in the female animal which produces the egg cell or ovum.

Ovum The female egg cell.

Parathyroids Small endocrine glands associated with the thyroid gland. The parathyroid hormone controls the concentration of calcium in the blood and its exchange between the blood and bones.

Peristalsis The muscular movements of the gut wall which move the food through the gut tube.

Pituitary gland The "Master" gland of the endocrine system because of its many controlling actions. It lies beneath the brain and is in fact attached to it by a stalk. It is divided into two main lobes, an anterior and posterior lobe. The former produces a number of hormones which between them promote growth, regulate metabolism and control the sex organs and adrenals. A posterior lobe secretion controls the loss and absorption of water through the kidneys and another is thought to have a controlling effect at birth in mammals.

Placenta A wedge of tissue in the uterus of the mother from which the embryo mammal receives food and oxygen up to the time of its birth.

Plasma A solution of many substances which forms the fluid part of the blood. It contains inorganic salts (e.g. the chlorides, sulphates and bicarbonates of sodium and potassium) and proteins such as albumin. Glucose, amino acids, fatty substances and hormones are also present. Plasma makes up about 55 per cent of the blood, the other 45 per cent being the corpuscles (see page 114).

Poikilotherm An animal which is unable to regulate its body temperature, e.g. snakes and other reptiles whose body temperature will vary with the temperature of the surroundings.

Proteins Complex organic compounds found in living material and an essential part of protoplasm. They are built up in the body from amino acids and contain carbon, hydrogen, oxygen, nitrogen and sometimes sulphur and phosphorus. They account for most of the nitrogen in the body and are incorporated in many hormones and enzymes.

Recessive factors Factors which are dominated by the dominant factors and do not appear in an organism when both are inherited.

Respiration Includes the exchange of oxygen and carbon dioxide in the lungs and tissues and also the chemical processes taking place within cells. Examples of the latter are the breaking down of carbohydrates in muscle to release energy for muscle contraction.

Sympathetic ganglia are concentrations of nerve cells within the autonomic nervous system (see above).

Sympathetic nervous system The old name for the autonomic nervous system.

Synapses The small gaps between the ends of nerve fibres across which impulses travel.

Thyroid gland An endocrine gland situated in the front of the neck. It produces one main hormone (thyroxine) which controls the rate at which body metabolism proceeds and affects the functioning of the nervous system. Excess production of thyroxine causes an increase in the metabolic rate and vice versa. Faults in the thyroid gland can have unpleasant effects such as goitre on the neck (lack of thyroxine) and myxoedema (excess thyroxine formation), a disease in which there is great swelling of body tissues. Lack of thyroid secretion in young people results in cretinism, when the child is very backward.

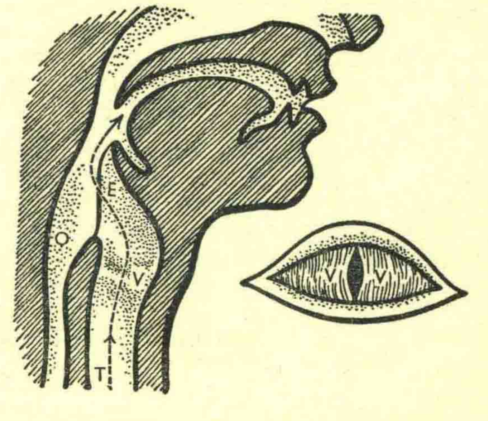
Thyroxine The hormone produced by the thyroid gland.

Tissue A group of cells within the body which share a common function. Examples are muscle tissue, connective tissue (bone, blood) and glandular tissue.

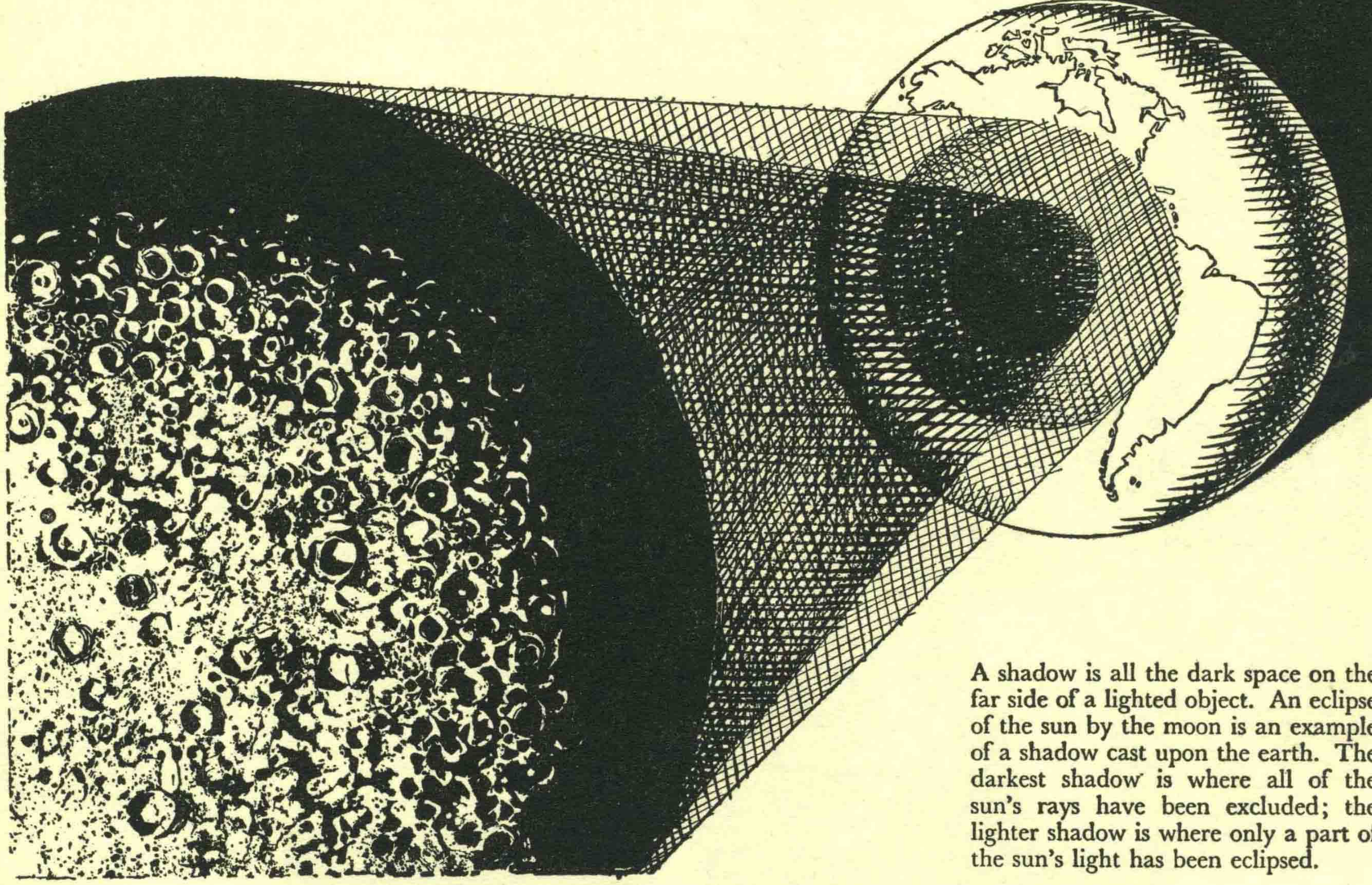
Villus A small projection of the lining of the small intestine. These are very numerous (see page 113) and increase the amount of absorption which can take place through the gut wall.

Vitamins Complex organic chemicals which are essential parts of the diet though only required in very small quantities. Usually each vitamin is known by a particular letter, though nowadays the chemical names are being used more and more. The most important in man are vitamins A, B, C, D and E. Vitamin A is needed to keep the linings of the nose and throat in good condition, to maintain the body's resistance to infection and to keep the eyes healthy. Extreme lack of it causes poor vision in the dark (night-blindness). It can be made in the body by the liver. Vitamin B consists of a number of vitamins known as B_1, B_2, etc. Lack of B_1 results in a skin disease, beri-beri, and in nervous disorders. It is found in yeast, wheat germ and meat. Vitamin B_2 is important in cell respiration. Lack of it results in ulcers in the mouth and the cornea of the eye. Lack of nicotinic acid, at one time confused with B_2, causes pellagra —a skin disease. Vitamin C occurs in fresh fruit and lack of it causes scurvy (a general bleeding of the tissues) and affects bone and teeth formation. Lack of Vitamin D causes rickets in which bone growth is very poor.

Vocal cords The human voice is produced by the vibration of two muscular membranes in the larynx called the vocal cords (V). Air from lungs passes through the trachea (T) and sets the cords in motion like the reed of a musical instrument. The sound produced causes resonance in the cavities shown in the diagram: the tongue alters the size of the cavities to give different vocal qualities. E=epiglottis. O=oesophagus (food passage).

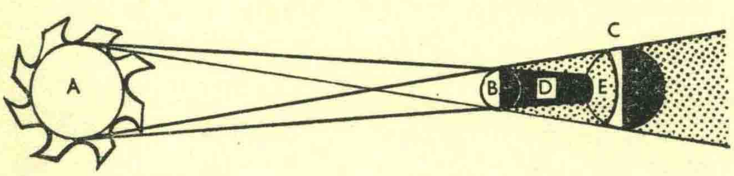


THE STUDY OF LIGHT

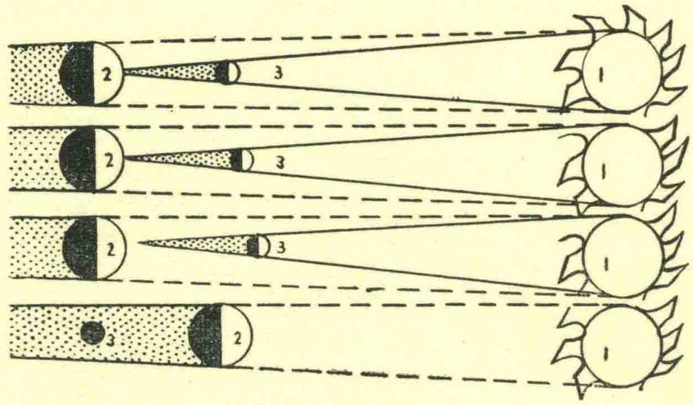


A shadow is all the dark space on the far side of a lighted object. An eclipse of the sun by the moon is an example of a shadow cast upon the earth. The darkest shadow is where all of the sun's rays have been excluded; the lighter shadow is where only a part of the sun's light has been eclipsed.

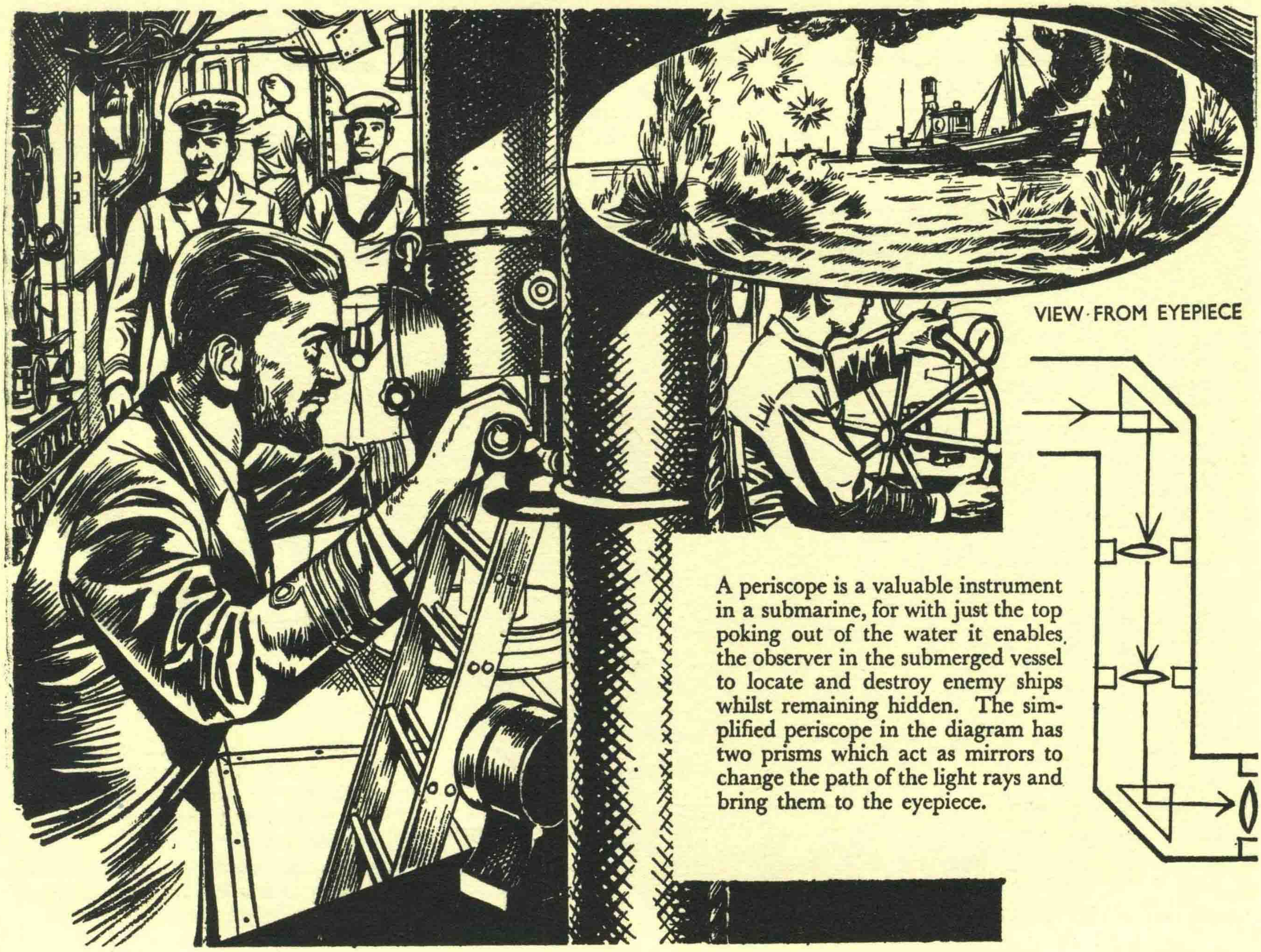
The nature of light is still a mystery, though at least two theories concerning its nature exist. For some purposes it is best to regard light as electromagnetic vibrations (i.e. akin to radio waves). Unlike sound, light does not need a material substance to travel in since it can travel across a vacuum—it comes to us from the sun across empty space. Optics is the name for the study of the behaviour of light.



An eclipse of the sun (A) by the moon (B) and its effect upon the earth (C). The umbra (D) is a region of complete shadow—where a total eclipse of the sun may be seen from the earth. The penumbra (E) is a region of partial shadow, growing lighter towards its outer margins, where a partial eclipse of the sun may be seen as pictured (*left*).



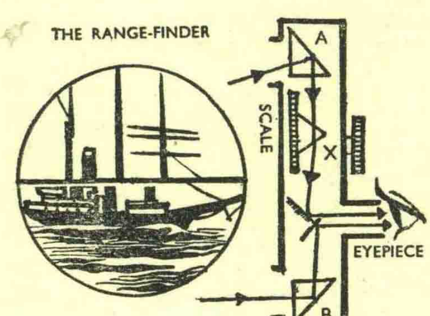
The shape and size of a shadow's profile depend on the position of the object between the light source and the reflecting surface. As the diagram above shows, in the case of an eclipse of the sun the size of the shadow thrown on the earth depends upon the position of the moon in relation to the earth and sun.



A periscope is a valuable instrument in a submarine, for with just the top poking out of the water it enables the observer in the submerged vessel to locate and destroy enemy ships whilst remaining hidden. The simplified periscope in the diagram has two prisms which act as mirrors to change the path of the light rays and bring them to the eyepiece.

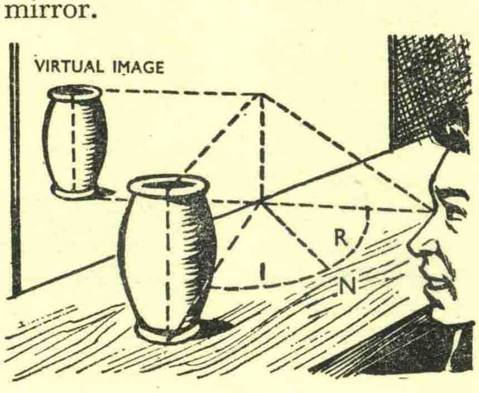
Reflection of Light

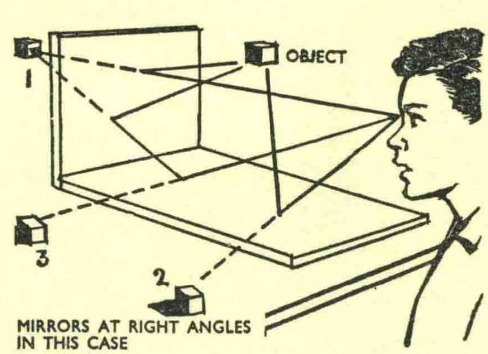
Nearly all of the light received upon the earth comes from the sun. Only a very small amount is produced in other ways (by candles, lamps and such). The reason why we see most earthly objects, such as trees, stones, books, and even the moon, is that they all reflect a certain amount of light into our eyes. A mirror is a highly polished surface which reflects nearly all of the light it receives. Mirrors therefore have many practical purposes, some of which are shown on this page.



Prism A reflects light from the top of the target and prism B from the bottom. The target top is displaced as rays at A make an acute angle with the range-finder. Moving prism X corrects this.

The diagram below shows that the angle of reflection (R) of an object always equals the angle of incidence (I). The *normal* (N) is an imaginary perpendicular to the mirror.

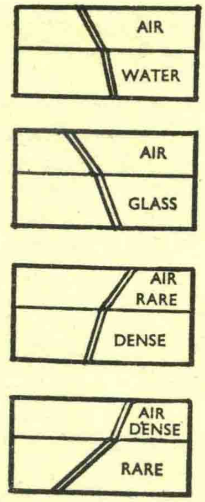




Two mirrors in different planes each form a direct image (1 and 2). In this case, image 1 is in such a position to the observer that he also sees an image of image 1—i.e. image 3.

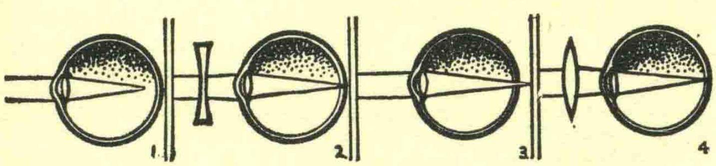
Refraction of Light

When light travels through any single medium (i.e. air or water) it does so in a straight line. The truth of this statement may be seen when a shaft of sunlight enters a dark room and lights up the dust particles in its path. But when light rays that have been travelling through one medium pass into another medium they change their direction. This "bending" of light rays is called *refraction.* The amount of refraction a light ray undergoes depends upon the difference between the density of the medium it is just leaving and the density of the medium it is just entering. The greater the difference the more the refraction. A light ray entering a different medium at a right angle, however, will not be refracted.



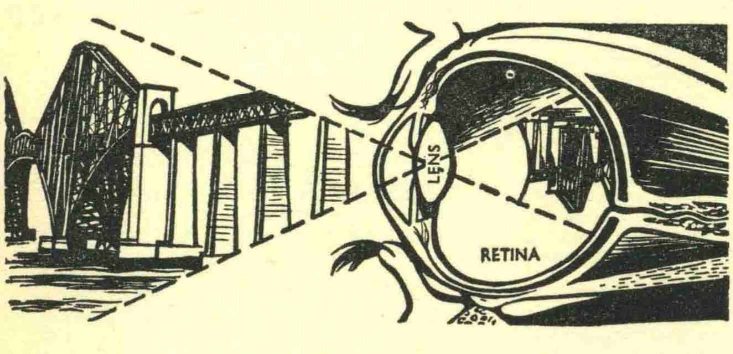
REFRACTION VARIES FOR DIFFERENT SUBSTANCES ACCORDING TO THEIR COMBINATIONS OF DENSE TO RARE OR RARE TO DENSE

The stick held by the man in the water appears to the reader to be bent, although actually it is straight. This illusion is brought about by the refraction of the light rays as they pass from the air into the water.

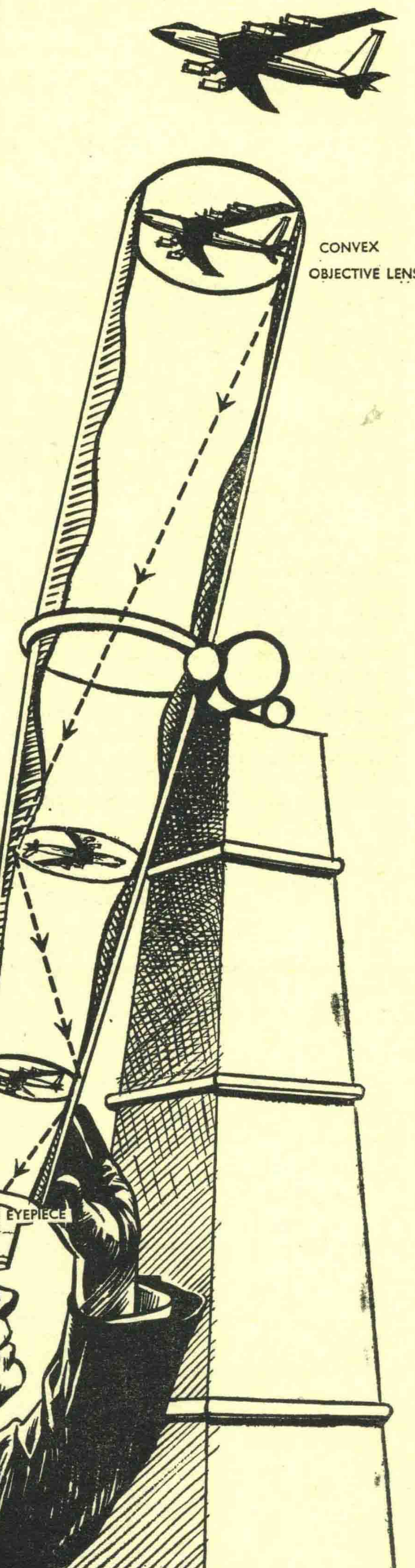


Short sight is corrected by the use of a concave lens and long sight by a convex lens.

IN SHORT SIGHT (1) THE LENS DOES NOT FOCUS THE IMAGE FAR ENOUGH BACK TO FALL ON THE RETINA. A CONCAVE LENS (2) CORRECTS THIS BY EXPANDING THE LIGHT BEAM. IN LONG SIGHT (3) THE IMAGE WOULD BE FORMED BEHIND THE RETINA. A CONVEX LENS (4) CORRECTS THIS BY CONVERGING THE LIGHT BEAM.

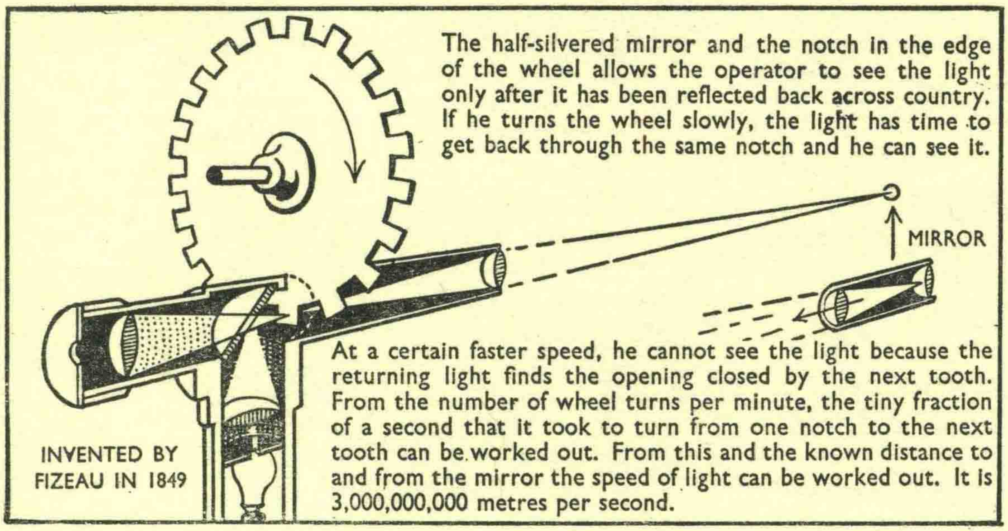


The eye is like a camera in which the film is a curved sheet of nerve tissue called the *retina.* The lens casts on the retina an upside-down picture but the brain "reads" this the right way up.



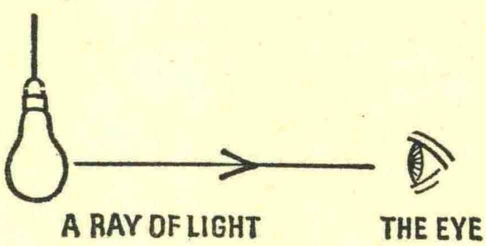
THE TERRESTRIAL TELESCOPE

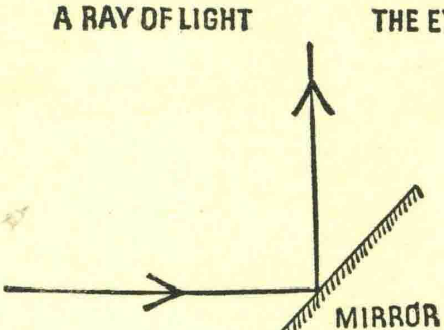
Light Theory



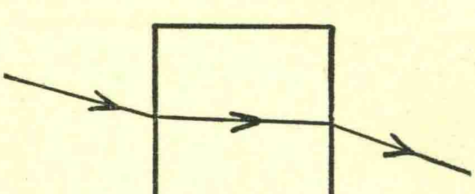
LIGHT

Light is a form of energy in the form of waves, travelling at 186,000 miles per second through space, almost as rapidly through air, and somewhat slower through transparent liquids and solids. In Physics, we usually consider very narrow slices of light waves, known as rays of light. We represent them as a straight line with an arrow-head, pointing away from the source of light. Rays of light travel in straight lines unless they are *reflected* at the surface of another substance or are *refracted* on passing into another substance.





A ray of light reflected.

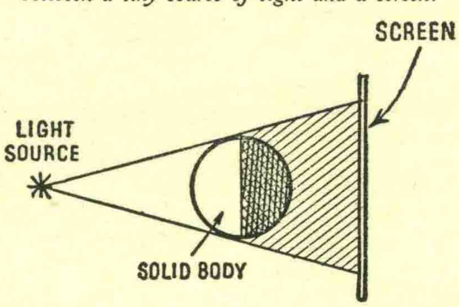


A ray of light refracted on passing through a block of glass.

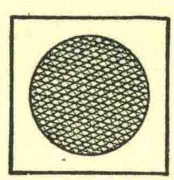
SHADOWS

When a solid body is placed between a source of light and a screen, certain areas are shielded from light by the solid body. Such areas are shadows.

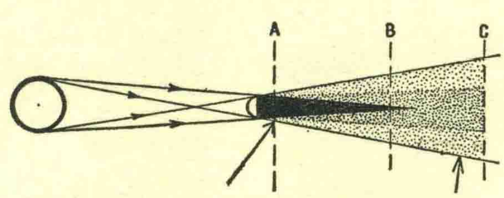
The shadow cast when a solid body is placed between a tiny source of light and a screen.



The appearance on the screen.



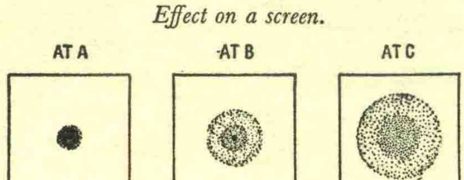
The shadow cast by a large luminous source, e.g. a "Silverlight" electric lamp, which is bright all over.



Umbra, complete shadow.

Penumbra, partial shadow; very deep near umbra, becoming fainter towards edges.

Effect on a screen.



INTENSITY OF LIGHT

The intensity of a source of light is usually given as so many "candle-power". There was, at one time, a special type of candle, giving exactly one candle-power, to serve as a standard. It was replaced by a very special type of lamp burning a special fuel, pentane, and giving exactly 10 candle-power; and later by a specially made electric lamp. The latest standard is a hole 1 sq. cm. in area through which can be seen the inside of a small furnace containing the metal platinum at its melting point. The intensity is about 60 candle-power. A new unit has been introduced, and the light given out by the hole in the furnace is exactly 60 "candelas".

The intensity of illumination on a surface is

(a) directly proportional to the candle-power of the lamp, e.g. 100 c.p. gives 100 times the intensity of illumination of 1 candle-power.

(b) inversely proportional to the square of the distance from the lamp, e.g. twice the distance, a quarter the intensity of illumination; three times the distance, one ninth; five times the distance, one twenty-fifth the illumination, and so on.

One foot-candle is the intensity of illumination when a lamp of 1 candle-power is placed 1 foot from the surface.

Example 1: A lamp of 100 candle-power is placed 3 feet above a table. What is the intensity of illumination?

1 c.p. 1 ft. away gives 1 foot-candle.

100 c.p. 1 ft. away gives 100 foot-candles.

100 c.p. 3 ft. away gives $\frac{100}{3 \times 3}$ foot-candles.

$= 11\frac{1}{9}$ foot-candles.

Example 2: For sewing, an intensity of 20 foot-candles is recommended. How far from the work should an electric lamp of 180 candle-power be placed in order to provide this intensity of illumination? Let the distance be d feet.

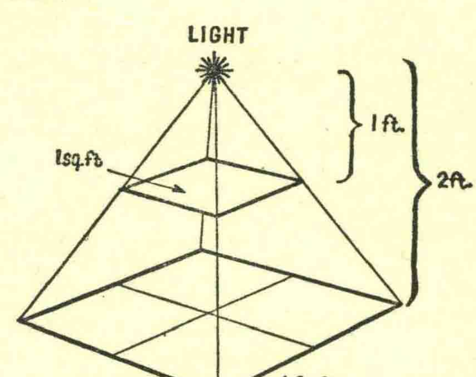
The intensity due to a lamp of 180 c.p. 1 foot away = 180 foot-candles.

The intensity due to a lamp of 180 c.p. d feet away $= \frac{180}{d^2}$ foot-candles.

This is 20 foot-candles, so $20 = \frac{180}{d^2}$

$\therefore 20\,d^2 = 180 \quad \therefore d^2 = 9 \quad \therefore d = 3.$

The lamp should be 3 feet away from the work.



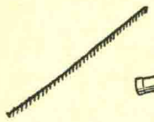
An illustration of the "Inverse Square Law".

THE REFLECTION OF LIGHT

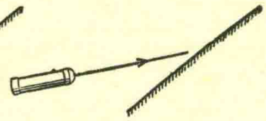
LAWS

(1) The angle of incidence is equal to the angle of reflection.

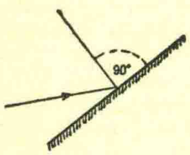
(2) The incident ray, the normal and the reflected ray are in the same plane. The meaning is that if the mirror is perpendicular to this page and the incident ray comes along the surface of the page, then the reflected ray is also along the surface of the page.



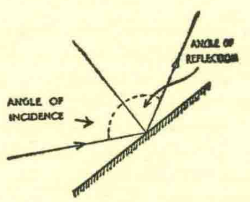
A mirror.



A mirror and an incident ray.



A mirror, an incident ray and a normal.



A mirror, incident ray, normal and reflected ray.

SOME USES OF PLANE MIRRORS

Plane mirrors, with their reflecting properties, have many practical purposes. They may be used, for instance, in inexpensive cameras as the view-finder or in simple periscopes for seeing over the heads of crowds. A plane mirror may also be used to reflect light into a window close to another building.

THE IMAGE

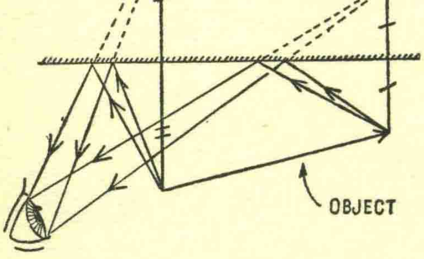
The position of an image in a mirror is:

(a) on the same normal as the object.

(b) as far behind the mirror as the object is in front.

It is also laterally inverted, e.g. ∟ looks like ┘.

The diagram below shows the rays by which the eye sees an image in a mirror.



Rays of light from the object enter the eye after reflection and *appear* to have come from behind the mirror.

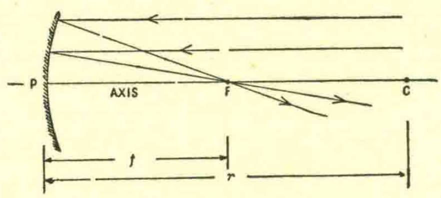
CURVED MIRRORS

A curved mirror is made from a piece of glass which would form part of a hollow glass ball. If silvered on the outside, it is a concave mirror; if on the inside, a convex mirror.

The axis (PC) of the mirror is the radius through its centre, the Pole. The Centre of Curvature is the centre of the sphere (C). The radius of curvature is the radius of the sphere (r). The Principal Focus (F) is the point through which all rays parallel to the axis pass (or appear to pass) after reflection.

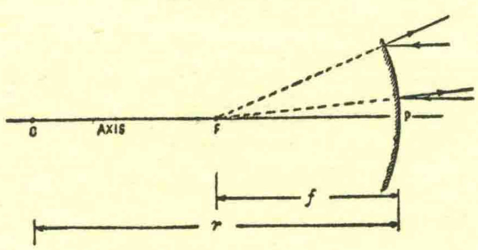
The focal length (f) is the distance between Pole and Principal Focus. Radius of curvature = 2 × focal length.

A concave mirror.



Note: r = 2f.

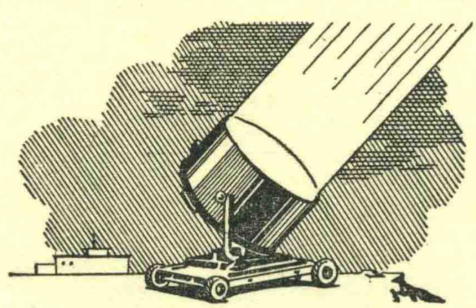
A convex mirror.

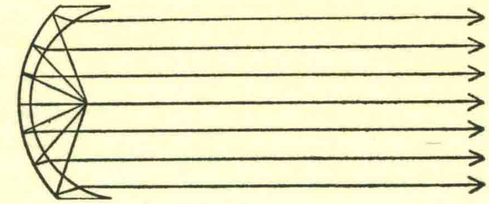


In this case the principal focus is an imaginary one, as rays do not go through it, but merely appear to have come from it after reflection.

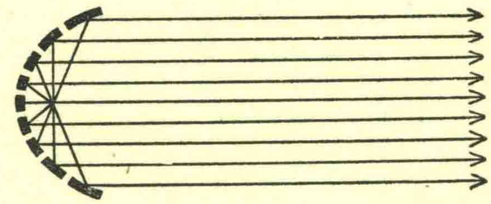
PRACTICAL APPLICATION OF CURVED MIRRORS

Curved mirrors have many useful applications, one of which—the searchlight—is shown below. The searchlight is based upon the fact that if a point source of light is placed at the principal focus of a concave mirror, after reflection the rays emerge as a parallel-sided beam.





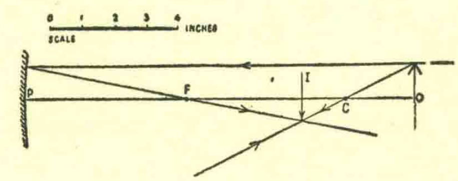
Mangin mirror.



Parabolic mirror.

Finding, by geometrical construction, the position and size of the image of an object in front of a concave mirror

Example: Radius of curvature 10 in., object 2 in. high, 12 in. from mirror.



Steps:

(1) Draw axis and mirror, marking in P, C and F (to scale).

(2) Mark in object (O) to scale.

(3) From head of object draw a ray parallel to the axis, and its reflected ray through F.

(4) From head of object draw a ray through C. This will always hit the mirror along a normal and come back along the same path. The point where the two reflected rays cross is the image of the top of the object.

(5) Draw in the remainder of the image (I) by symmetry.

Description of image:

It is real, because reflected rays actually go there.

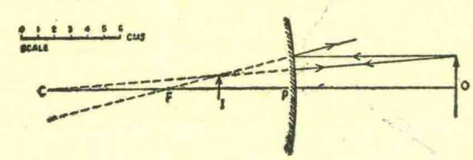
It is inverted.

It is 1·4 in. tall.

It is 8·6 in. from the mirror.

Finding, by geometrical construction, the position and size of an image in a convex mirror

Example: Radius of curvature 15 cm., object 4 cm. high and 10 cm. from mirror.



Construction exactly as before, except that rays behind mirror are imaginary and therefore dotted. The image is imaginary too—"virtual" is the special name for such an image.

Image is virtual, upright, 1·8 cm. tall, and 4·5 cm. behind mirror.

THE MIRROR FORMULAE

(a) $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

$$\left.\begin{array}{l} u = \text{distance of object} \\ v = \text{distance of image} \\ f = \text{focal length} \end{array}\right\} \begin{array}{l}\text{all measured}\\ \text{from the}\\ \text{mirror.}\end{array}$$

Note: Real things—POSITIVE.

Virtual things—NEGATIVE.

(b) Magnification $= \frac{I}{O} = \frac{v}{u}$

I = size of image; O = size of object. In this equation, signs are ignored.

Example 1: Concave mirror of radius of curvature 12 in. Object 4 in. high, 8 in. from mirror. Find the position and height of the image.

$u = +8.\ f = +6.\ v = ?.$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \qquad \frac{1}{+8} + \frac{1}{v} = \frac{1}{+6}$$

$$\therefore \frac{1}{v} = \frac{1}{+6} - \frac{1}{+8} = \frac{1}{6} - \frac{1}{8} = \frac{4-3}{24} = \frac{1}{24}$$

$v = +24.$

There is a real image 24 in. from mirror.

$$\frac{I}{O} = \frac{v}{u} \therefore \frac{I}{4} = \frac{24}{8} = \frac{3}{1}$$

$\therefore I = 3 \times 4 = 12$ in. tall.

Example 2: Concave mirror, focal length = 9 in. Object 6 in. from mirror. Find magnification.

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{+6} + \frac{1}{v} = \frac{1}{+9}$$

$$\frac{1}{v} = \frac{1}{+9} - \frac{1}{+6} = \frac{1}{9} - \frac{1}{6} = \frac{2-3}{18} = -\frac{1}{18}$$

$$\therefore v = -18$$

Image is virtual, and 18 inches behind mirror.

Magnification $= \frac{v}{u} = \frac{18}{6} = 3.$

Note: All real images are inverted, and all virtual images are upright.

Example 3: Convex mirror, focal length 10 cm., object 20 cm. from mirror. Find magnification.

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{+20} + \frac{1}{v} = \frac{1}{-10}$$

$$\frac{1}{v} = \frac{1}{-10} - \frac{1}{+20} = \frac{-1}{10} - \frac{1}{20} = \frac{-2-1}{20}$$

$$= \frac{-3}{20}$$

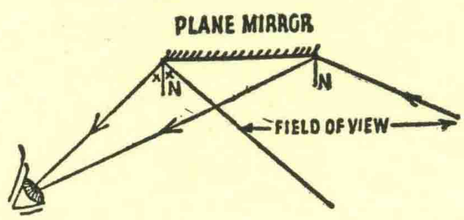
$$\therefore v = \frac{-20}{3} = -6\tfrac{2}{3}.$$

Magnification $= \frac{v}{u} = \frac{6\frac{2}{3}}{20} = \frac{20}{3} \div 20 = \frac{1}{3}.$

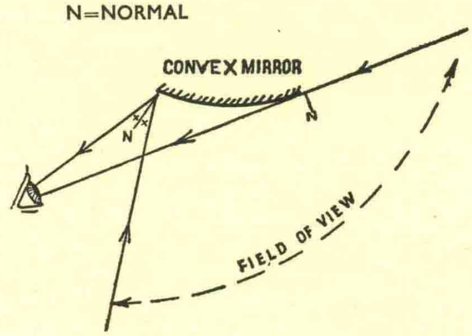
The image is virtual (because of negative sign), upright (because it is virtual) and one-third the size of the object.

The convex driving mirror gives a greater field of view for the motorist.

N=NORMAL

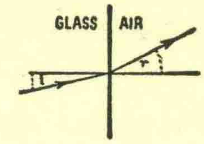


N=NORMAL



Best of all is the cylindrical mirror, which gives a very wide view in the horizontal plane, but a normal field of view in the vertical plane—it shows both sides of the road, but not the road surface nor the sky above.

Example 2: Glass into air.



$$\hat{r} > \hat{i}$$

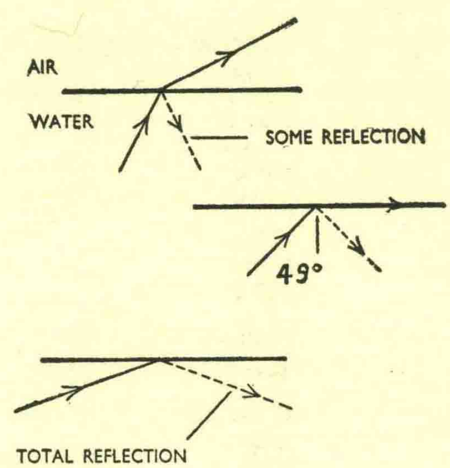
Ray is bent away from the normal.

General Rule: When a ray of light passes from a dense substance (e.g. glass) into a less dense (e.g. air) it is refracted away from the normal, unless it approaches the surface of separation along the normal, when its path is unchanged.

TOTAL INTERNAL REFLECTION

Reflection always takes place from a surface when refraction takes place through it. At a certain angle of incidence, however, the refracted ray passes along the surface of separation. This is called the *critical angle.* When the angle of incidence is greater than the critical angle, refraction cannot take place and *all* the light is reflected back into the substance.

Critical angle for water	= 49°
Critical angle for glass	= 42°
Critical angle for diamond	= 25°



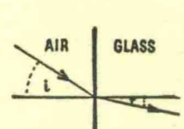
Explanation of refraction: Change in speed of light on passing from one transparent substance to another of different density.

THE REFRACTION OF LIGHT

Refraction is the bending of light as it passes from one transparent substance into another, e.g. from air into glass, or from water into air.

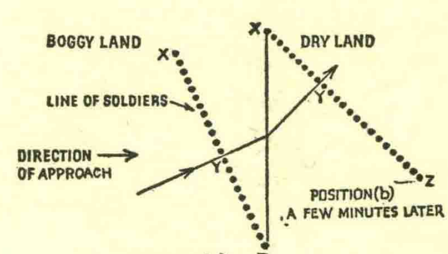
Refraction varies for different substances in their combinations of dense to rare, or rare to dense. If a light ray strikes another medium along its normal there is no refraction—if you look straight down into water you see a stone at the bottom in its true direction. The amount of bending at any surface is standard, so a too oblique approach from dense to rare will result in reflection, not refraction.

Example 1: Air into glass.



Angle of incidence > angle of refraction: ray is bent towards the normal.

Compare with a long line of soldiers, on boggy land, and just reaching firm land.



Private Z has been on firm land the whole time, so has gone a long way. Private

X has been in the swamp and has moved forward slowly. Y has had some good and some bad going. As a result the whole line has wheeled round—has been "refracted".

Refractive index of light passing from air into glass, written $a\mu g$ (μ is pronounced "mu")

$$= \frac{\text{speed of light in air}}{\text{speed of light in glass}} = \frac{3}{2}.$$

$a\mu g$ is also the sine of the angle of incidence divided by the sine of the angle of refraction.

$$a\mu g = \frac{\sin i}{\sin r}$$

Refractive indices	
Air to glass	$1{\cdot}50 = \frac{3}{2}$
Air to water	$1{\cdot}33 = \frac{4}{3}$
Air to diamond	2·40
Air to ice	1·31
Air to paraffin oil	1·44

CALCULATIONS ON REFRACTIVE INDEX

Example 1: A ray of light passes from air to glass with an angle of incidence of 30°. Find angle of refraction.

$$a\mu g = \frac{\sin i}{\sin r} = 1{\cdot}5.$$

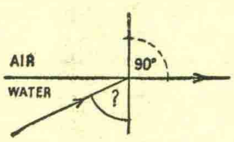
From mathematical tables, "Natural sine" of $30^\circ = {\cdot}5$.

$$\therefore a\mu g = \frac{{\cdot}5}{\sin r} = 1{\cdot}5 \qquad \therefore \sin r = \frac{{\cdot}5}{1{\cdot}5} = \frac{1}{3}$$

$$= {\cdot}333$$

From the tables again, the angle with a "Natural sine" of ·333 is 19°, so angle of refraction is 19°.

Example 2: What must be the angle of incidence of a ray of light passing from water into air for the refracted ray to skim along the surface?



$$a\mu w = \frac{4}{3} \qquad w\mu a = \frac{3}{4}$$

$$\frac{\sin i}{\sin 90^\circ} = \frac{\sin i}{1} = \frac{3}{4} \quad \therefore \sin i = \frac{3}{4} = {\cdot}75$$

$$\therefore \hat{i} = 49^\circ.$$

THE GEOMETRICAL METHOD FOR CONSTRUCTING REFRACTED RAYS

Step 1: Draw surface and incident ray.

Step 2: Draw the two circles in proper proportion (radii 3 and 2 for glass; 4 and 3 for water).

Step 3: Draw perpendicular where circle representing *denominator* of refractive index $\left(\text{e.g. 2 for } a\mu g = \frac{3}{2}\right)$ cuts incident ray.

Step 4: Draw refracted ray from point where perpendicular ray cuts the circle representing the numerator $\left(3 \text{ for } a\mu g = \frac{3}{2}\right)$.

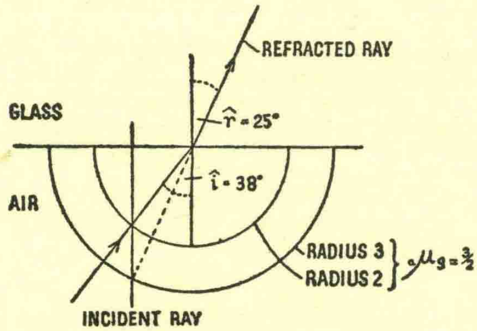
Example (a) is one of this type.

Example (b) deals with $w\mu a = \frac{3}{4}$.

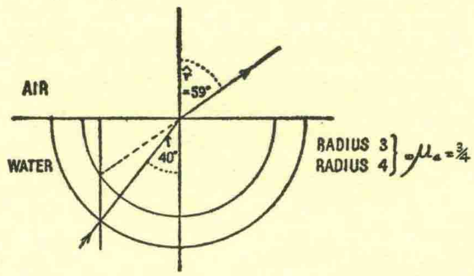
Example (c) finds the critical angle for $w\mu a = \frac{3}{4}$.

Example (d) will not work ∴ no refraction ∴ total internal reflection.

Example (a)

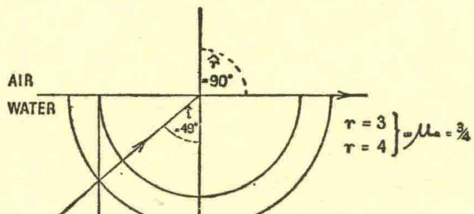


Example (b)



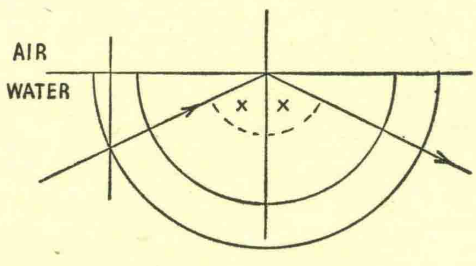
Example (c)

The critical angle of water.



Example (d)

Total internal reflection with water.

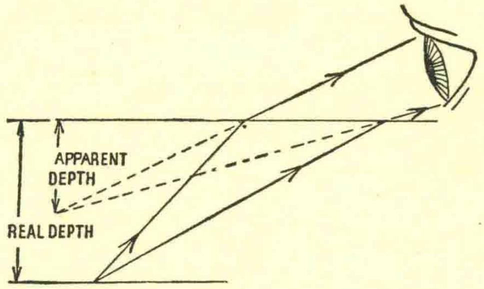


Remember, angle of incidence = angle of reflection.

APPARENT DEPTH

Due to refraction, a transparent material looks less deep than it really is.

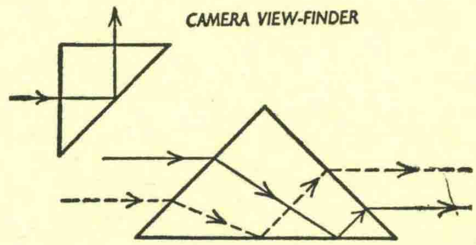
Explanation:



If one looks vertically downward, the apparent depth of water = $\frac{3}{4}$ the real depth. ($w\mu a = \frac{3}{4}$); and of glass, $\frac{2}{3}$ the real depth ($g\mu a = \frac{2}{3}$).

USEFUL APPLICATION OF TOTAL INTERNAL REFLECTION

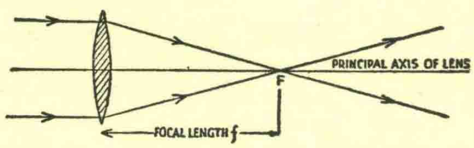
Some common uses of this principle are pictured below. In each case a right-angled glass prism is used. The angle of incidence, always 45°, is greater than the critical angle of 42°.



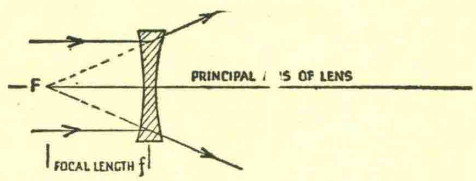
TO MAKE AN INVERTED IMAGE UPRIGHT

LENSES

A *convex* lens is a converging lens—it has a real principal focus.



A *concave* lens is a diverging lens—it has a virtual (imaginary) principal focus.



The principal focus of a lens (F) is the point to which light parallel to the principal axis is converged, or from which it appears to diverge, after refraction through the lens.

The focal length is the distance between the centre of the lens and the principal focus.

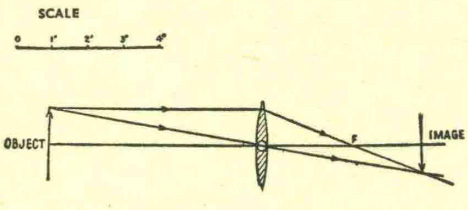
Geometrical Construction for Lenses:

(1) A ray from the top of the object, parallel to the principal axis, is refracted through the principal focus.

(2) A ray from the top of the object passes through the centre of the lens unchanged in direction.

(3) The point of intersection of the two rays gives the position of the top of the image. The bottom is drawn in symmetrically.

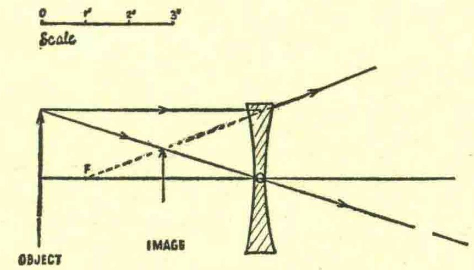
Example 1: An object of length 2 in. is placed 6 in. in front of a convex lens of focal length 2·5 in. Find position and size of image.



O = centre of the lens.

The image is inverted. It is 4·3 in. from the centre of the lens and 1·4 in. long.

Example 2: An object 3 in. tall is 5 in. from a concave lens of focal length 4 in. Give the position and size of the image.



The image is upright and virtual, being on the same side of the lens as the object and seen by looking through it. It is 2·2 in. from the lens and 1·3 in. tall.

The power of a lens. A lens of short focal length is a powerful lens.

The Dioptre. This is the unit of power employed by opticians. It is the focal length of a lens (in metres) divided into one.

Examples: Convex lens, focal length 1 m. (100 cm.):

$$\text{Power} = \frac{1}{+1} = +1 \text{ dioptre.}$$

Convex lens, focal length ½ m. (50 cm.):

$$\text{Power} = \frac{1}{+\frac{1}{2}} = +2 \text{ dioptres.}$$

Concave lens, focal length 2 m.:

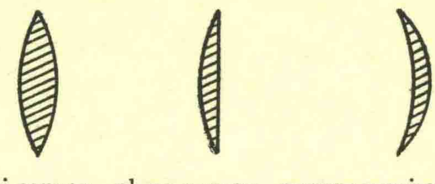
$$\text{Power} = \frac{1}{-2} = -\tfrac{1}{2} \text{ dioptre.}$$

Combined lenses. A convex lens of power + 4 dioptres is combined with a concave lens of − 3 dioptres. The power of both lenses together = the sum of their individual powers = + 4 dioptres + (− 3) dioptres = (4 − 3) = + 1 dioptre.

The combination has the power of + 1 dioptre, i.e. it behaves like a convex lens of focal length 1 m.

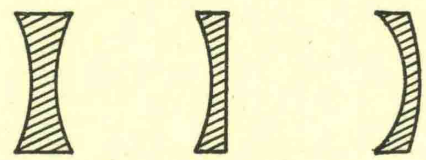
The aperture of a photographic lens. The "exposure" in photography depends upon the strength of the light and on the "aperture" of the lens. This is stated as an "f number", e.g. f4·5. This really should read $\frac{f}{4{\cdot}5}$, for, in this case, the diameter of the hole through which light enters the camera, through the lens, is the focal length ÷ 4·5. If a lens has a focal length of 9 in., and the diameter is 1 in., the aperture $= \frac{f}{9}$, i.e. f/9 or f9.

Types of lenses met in practice.



bi-convex plano-convex convex-meniscus

$\underbrace{\qquad\qquad\qquad\qquad}_{\text{convex or converging}}$



bi-concave plano-concave concave-meniscus

$\underbrace{\qquad\qquad\qquad\qquad}_{\text{concave or diverging}}$

COLOUR

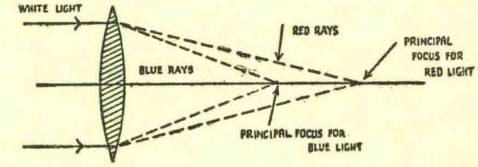
Light is a wave-motion like radio and radiated heat. Different colours have different wave-lengths.

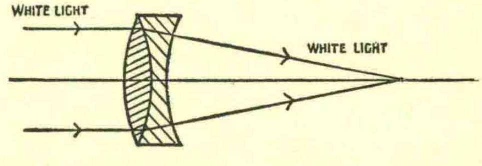
APPROXIMATE WAVE-LENGTHS	
Violet	425×10^{-9} metres, i.e. ·000000425 metres
Blue	475×10^{-9} metres
Green	525×10^{-9} metres
Yellow	575×10^{-9} metres
Orange	615×10^{-9} metres
Red	650×10^{-9} metres

Complementary colours are two colours which produce white when *added* together (e.g. by shining lamps of the two colours on to the same screen, not by mixing paints).

Examples: Red and peacock blue
Yellow and blue.
Green and magenta.

Compound lenses. A simple lens refracts light of different colour slightly differently, so if the image of a blue object is sharply in focus that of a red one in the same position is blurred because it is "out of focus".

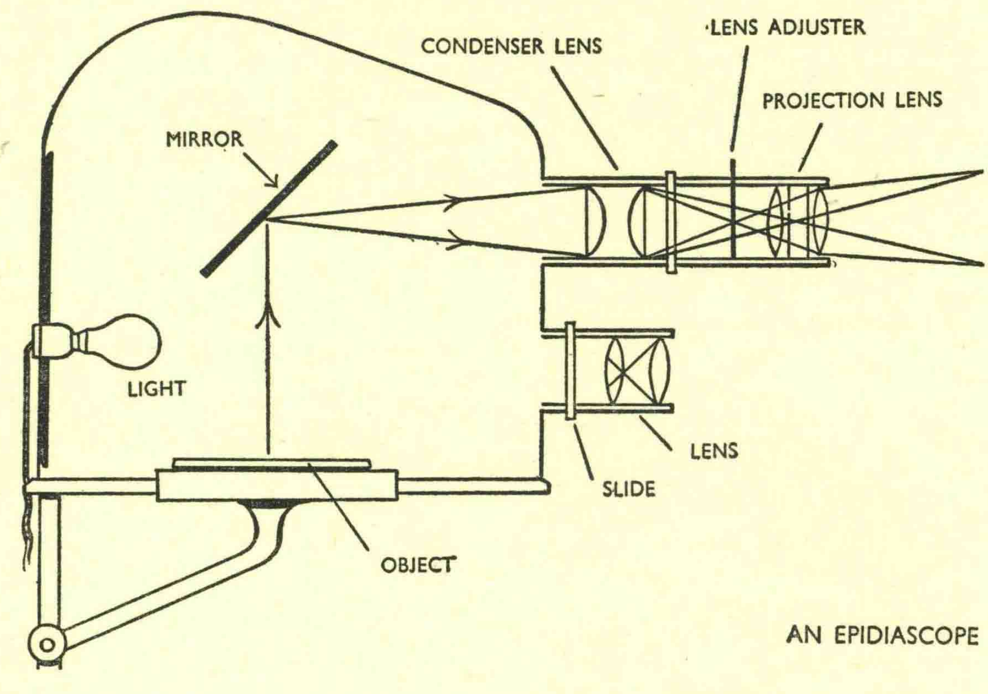




An achromatic lens, corrected for colour. The lenses are of different glass.

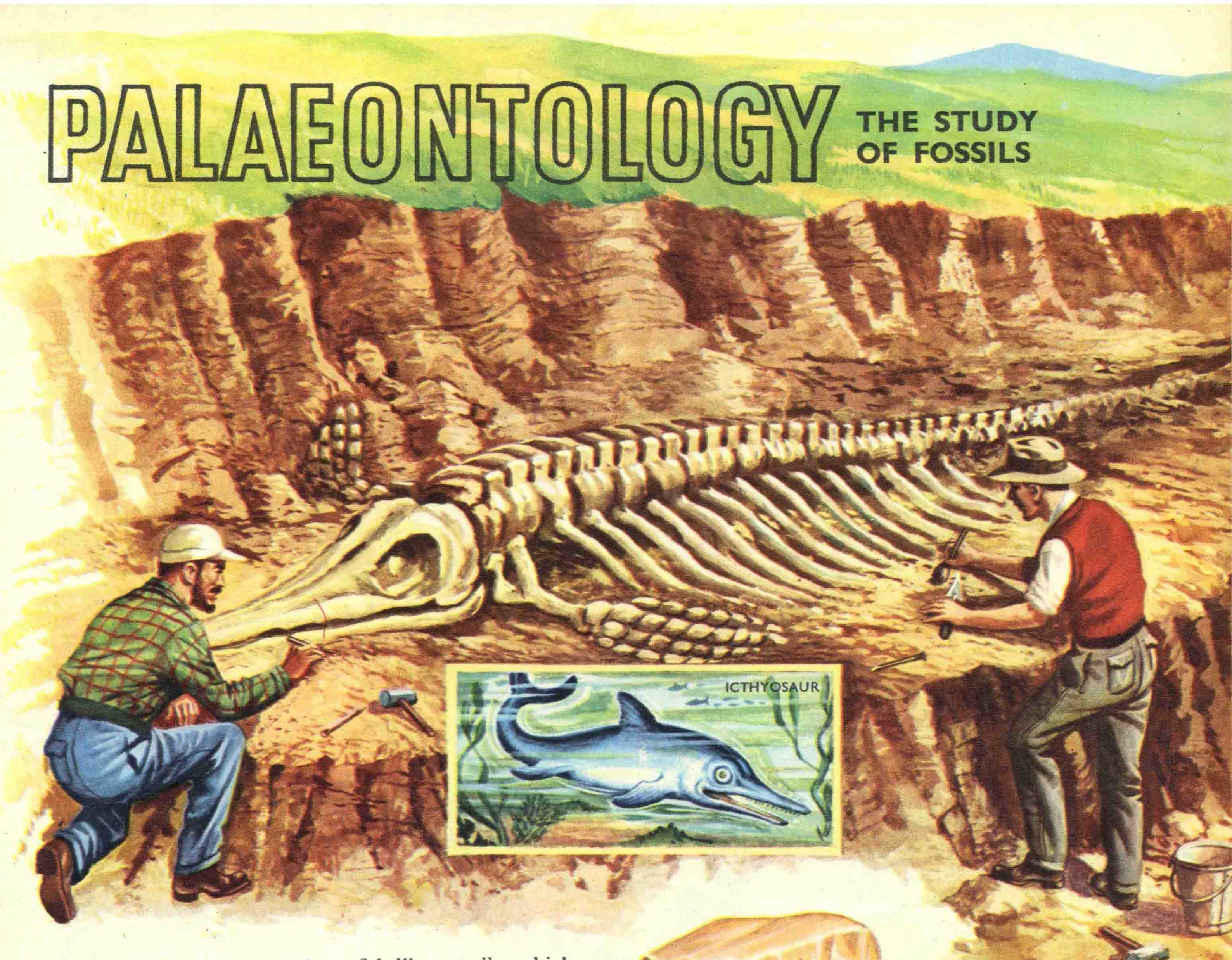
SOME COMMON USES OF LENSES

Among many other instruments, lenses are used in microscopes (both simple and compound), cameras and telescopes (both astronomical and terrestrial). The illustration below explains the action of the lens in an epidiascope.



AN EPIDIASCOPE

PALAEONTOLOGY THE STUDY OF FOSSILS

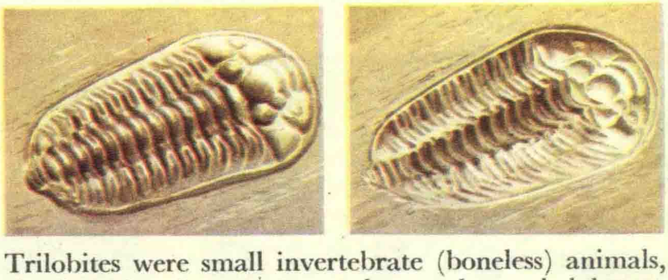


The icthyosaur was a giant fish-like reptile which became extinct over 100 million years ago. The rocks containing this excellent fossil have been exposed by erosion

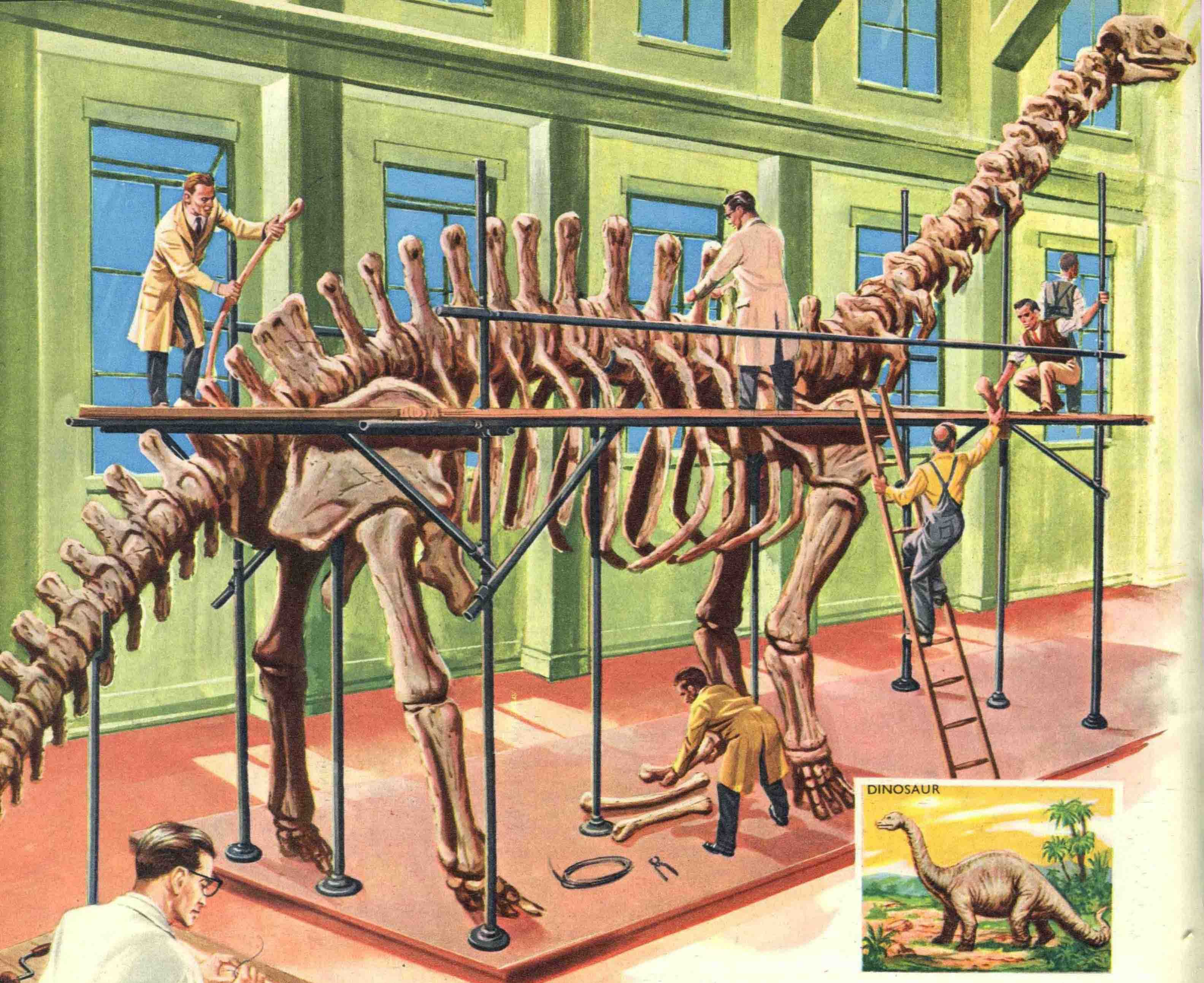
Millions of years ago, the insect pictured above became trapped in gum dripping from a tree. Gradually the gum hardened into amber and preserved the insect intact in every detail through the ages.

Palaeontology is the study of life in ages past as seen through fossils. Fossils are the remains of animals or plants which have been preserved in various ways, sometimes for millions of years.

When an animal dies it usually decomposes or is eaten by other animals. But the hard parts—the bones and teeth—are not as easy to destroy. The skeletons of fish, for instance, millions of years ago sank to the bottom of the sea. There they were covered with mud and silt which in time became solid rock. Then earth movements raised the rock layers above the waves. In fact the fossils of ancient sea-dwelling animals have been found at the tops of mountains which proves that the rock layers in which they were embedded, must, at one time, have been at the bottom of the sea.



Trilobites were small invertebrate (boneless) animals, closely related to present day crabs and lobsters. They became extinct over 200 million years ago. The first picture shows the petrified cast of a trilobite, the second a mould or impression. (See page 130.)



Some species of dinosaurs are thought to have been the largest land animals ever to inhabit the earth. Skeletons of these great reptiles (extinct for 100 million years) have been assembled in some museums.

The footprints of a dinosaur were discovered by a scientific expedition at the side of an old water course in the Gobi Desert. Casts were made of these unusual traces of the past.

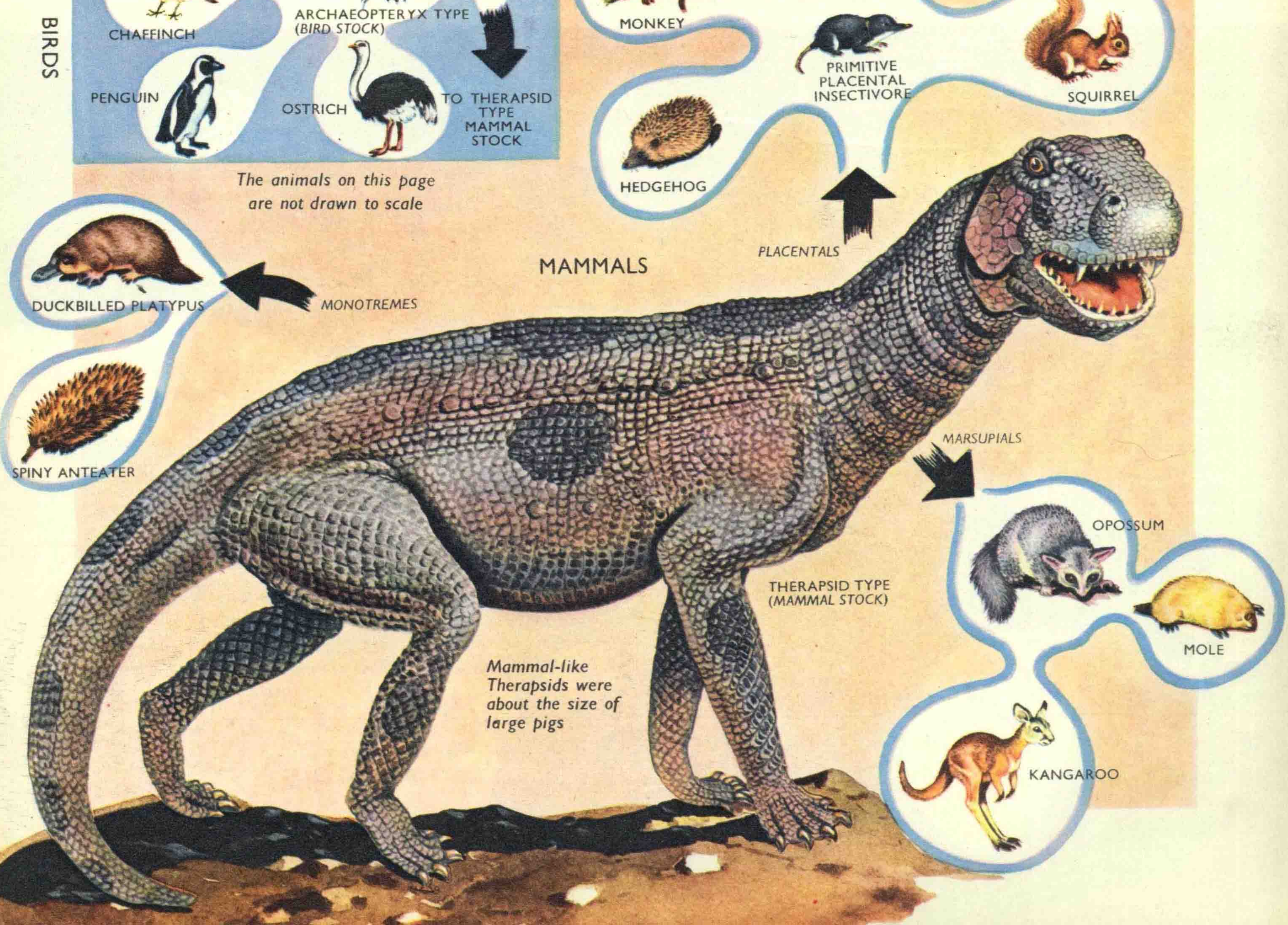
Buried skeletons of animals are often eaten away. But sometimes, the *impression* of the bones remains imprinted on the rocks, giving a clear picture of the animal's structure. The ancient tar pits of California, for instance, which trapped many large animals in prehistoric times, have yielded up many valuable fossils during recent excavations. In northern Siberia, mammoths (the forerunners of present day elephants), have even been preserved intact in ice !

Petrified remains of animals also count as fossils. In this case the bones are slowly eaten away and replaced by minerals until a perfect rock *cast* is produced.

The Evolution of Animals

Fossils help to explain the changing pattern of life through the ages. From them, a general picture of the evolution of animals has gradually been built up. But many more fossils will have to be found before the links between the main groups of animals—fishes, amphibians, reptiles, birds and mammals—become clear. So little is known about the earliest forms of life—probably single-celled marine organisms—that the chart below begins with the development of fishes. This probably took place over 400 million years ago.

The animals on this page are not drawn to scale



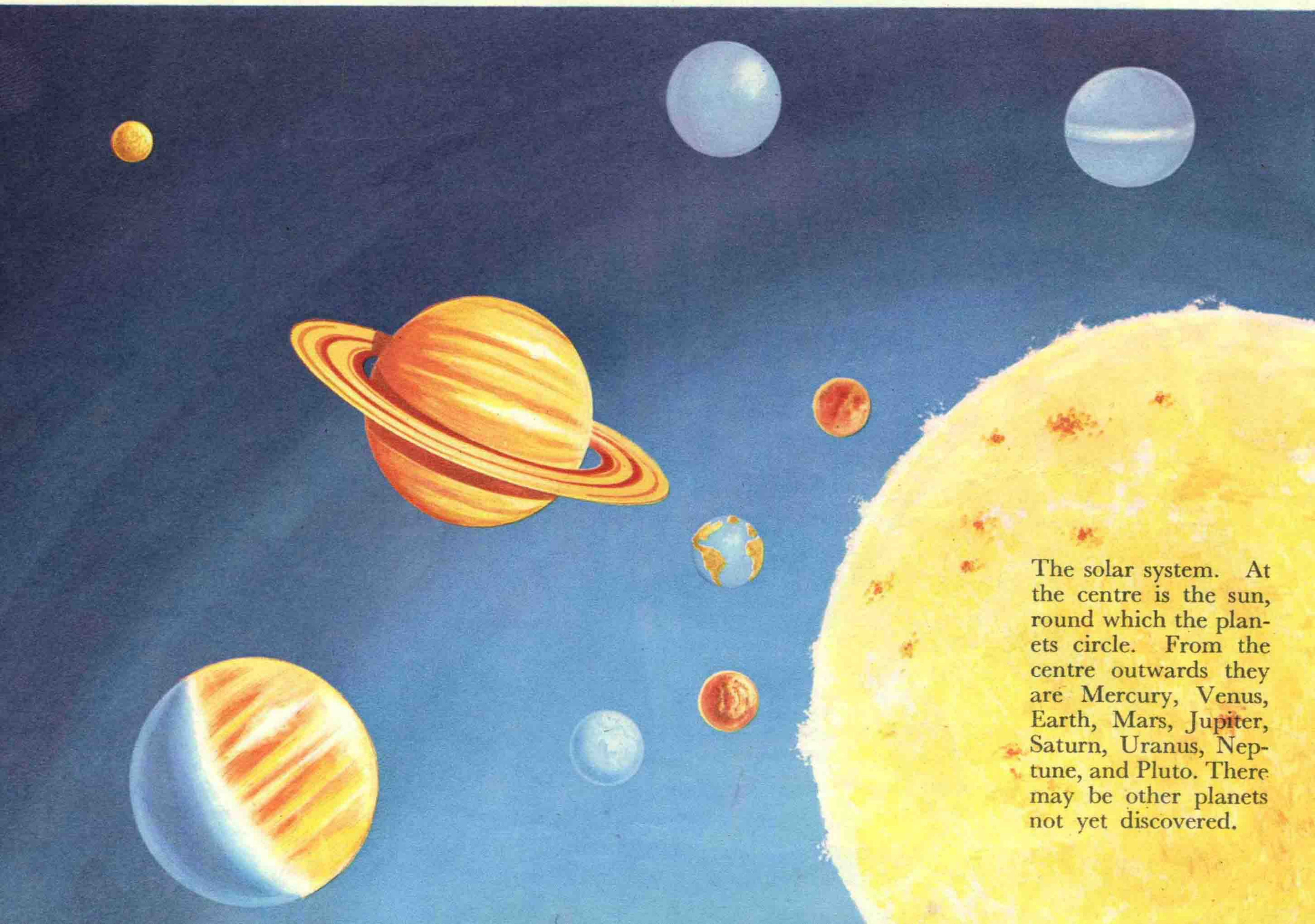
The Science of
ASTRONOMY

From earliest times man has been fascinated by looking up at the heavens. The night sky is a rewarding subject for the astronomer, and in recent years apparatus has been developed whereby observations can also be made in full daylight.

One difficulty which sometimes faces the budding astronomer is why the stars appear to move across the sky. In fact the apparent movement is caused by the spin of the earth, revolving on its axis once every twenty-four hours. Most stars are so far away that only comparatively small movements can be detected after lengthy observation. The apparent differences in the positions of stars at different times of the year are largely due to the fact that the earth moves round the sun in an elliptical orbit, which takes about $365\frac{1}{4}$ days to complete. Since the orbit is approximately 186 million miles across *at its narrowest point*, considerable changes in the relative positions of the stars may be noticed.

As the earth spins round on its axis, some parts of the heavens become visible to an observer, others disappear. The west to east rotation of the earth makes it appear that the sky is moving from east to west.

One other factor is important. The earth is tilted at a constant angle of $66\frac{1}{2}°$ to the line of its path round the sun. This means that the North Pole, for example, is always facing in the same direction. Therefore, most stars which can be seen in the northern hemisphere cannot be seen in the southern hemisphere, while many of those visible in the south cannot be seen in the north.



The solar system. At the centre is the sun, round which the planets circle. From the centre outwards they are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. There may be other planets not yet discovered.

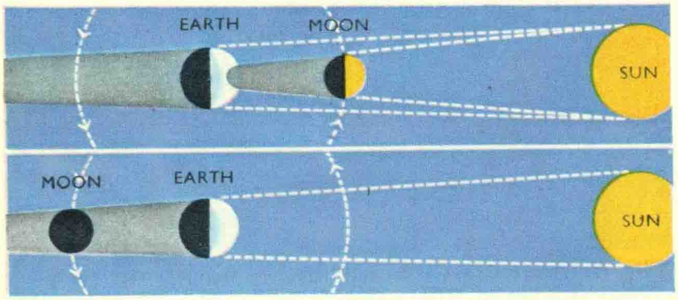
The Solar System

THE SUN. The sun is a globe of incandescent gas, mainly hydrogen, with a surface temperature of about 6,000° C. Its equator has a diameter of 864,000 miles. Sunspots, areas less bright than the rest of the surface, appear at random. The sun rotates on an axis, but being gas, not all the surface turns at the same rate.

The planets and the sun round which they revolve are known as the solar system. In fact, this is but a tiny part of the great galaxy of stars. The Milky Way, which we see in the night sky as a blur of white light, is made up of thousands of stars and is another part of the galaxy.

The reason why the planets continue to circle the sun is that they are held by a gravitational pull, the attraction between masses. Centrifugal force prevents them from being pulled towards the sun. A comparison may be made between this and a boy swinging a stone on a string round his head. The boy represents the sun, the string the force of gravity, pulling inwards, while the stone is held outwards by centrifugal force. It is not possible to say exactly why the planets began to revolve round the sun in the first place, though most theories suggest that they were originally part of the same mass as the sun, whether as gas or solid.

Most of the planets in the solar system have their own satellites or moons, which circle them. Jupiter has at least twelve, and Saturn nine. Earth, however, has only the moon which moves round it about every $27\frac{1}{4}$ days.



Eclipses are of two kinds. An eclipse of the sun on earth is caused by the moon passing in between. An eclipse of the moon is caused by the earth passing between it and the sun (see also page 121).

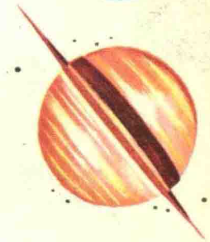
MERCURY. The planet nearest to the sun, Mercury is 3,100 miles in diameter, and has no atmosphere or satellites. It rotates on its axis in phase with its orbit, so that it always presents the same face to the sun. That side is much hotter than the other which is always dark. It is 36,000,000 miles from the sun.

VENUS. Venus is 7,680 miles in diameter, and rotates on its axis once about every 30 days. It is 67,300,000 miles from the sun. It has no satellites, but it probably has a cloudy atmosphere, which reflects a bright white light. Probably it always presents the same face to the sun, though this is not certain.

EARTH. Our planet is 7,900 miles in diameter, and has an atmosphere and a satellite, the moon, which circles it every $27\frac{1}{4}$ days. The earth is 93,000,000 miles from the sun, and completes its orbit round the sun in $365\frac{1}{4}$ days. It spins on its axis once every 23 hours 56 minutes. The moon always presents the same face to the earth.

MARS. Mars has a diameter of 4,220 miles, and is 141,700,000 miles from the sun. It spins on its axis once every 24 hours 37 minutes. It has a thin atmosphere, and its surface is crossed by canal-like depressions. It appears to reflect light of a reddish hue. Mars has two satellites, one of which circles it every $30\frac{1}{4}$ hours, the other every 8 hours.

JUPITER. The largest of the planets, Jupiter has a diameter across the equator of 88,700 miles, and is 483,900,000 miles from the sun. The spin on its axis takes only 9 hours 50 minutes to complete. Jupiter has at least 11 satellites which range in the time they take to circle it from 12 hours to 745 days. It has an atmosphere.



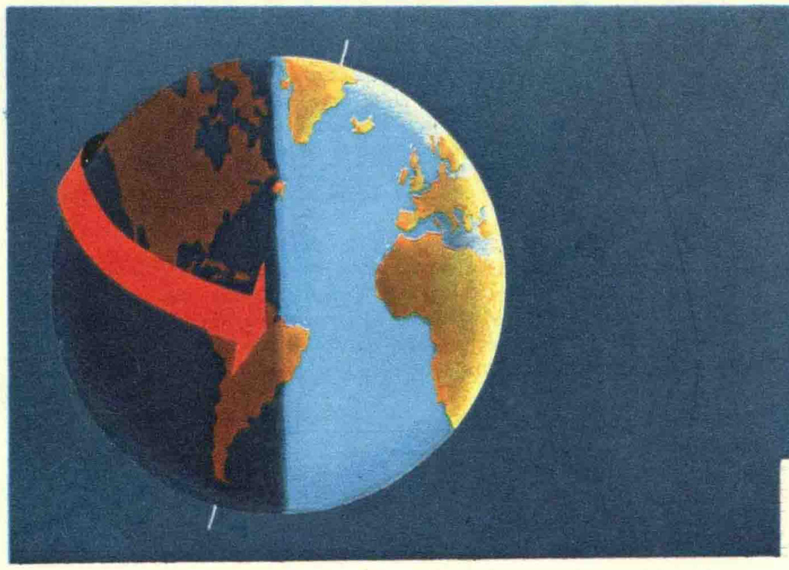
SATURN. The planet is 75,100 miles in diameter, and is 887,200,000 miles from the sun. It rotates on its axis once every $10\frac{1}{4}$ hours. It has nine satellites as well as the Ring System, made up of tiny " moons " only a few inches in size, which gives it its characteristic appearance. Much of Saturn is probably made of gaseous material.

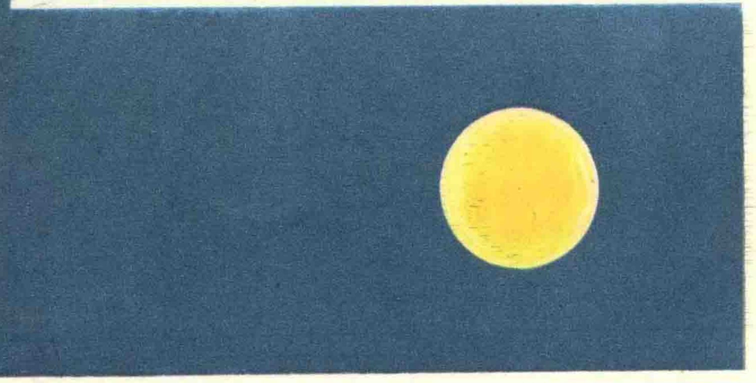
URANUS. Uranus is 31,800 miles in diameter and 1,784,000,000 miles from the sun. It has five satellites. The planet revolves on its axis once every $10\frac{3}{4}$ hours. It probably has an atmosphere about four miles thick. The reflected light from it has a greenish tinge. Temperatures are very low —over 200° C. below freezing.

NEPTUNE. The planet has a diameter of 27,800 miles, and is 2,797,000,000 miles from the sun. It turns on its axis once every $15\frac{3}{4}$ hours. Neptune has an atmosphere, probably about 25 miles thick. It has two satellites, one of which takes nearly six days to circle Neptune, the other 359 days. The latter has been known only since 1950.

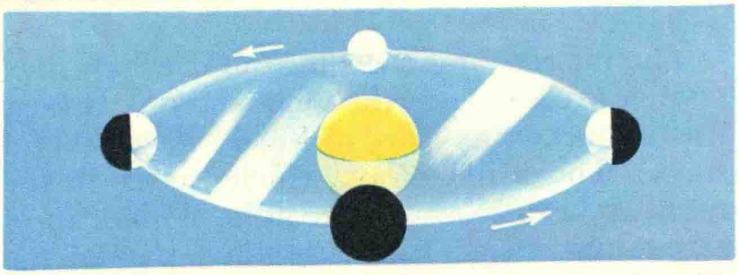
PLUTO. The second smallest of the major planets, Pluto has a diameter of 3,600 miles, and is 3,670,000,000 miles from the sun. The period of its rotation is about 6 days. No satellites have been discovered so far. The planet is so distant from us that little has been discovered about it. It has been known only since 1930.

Time and Tide



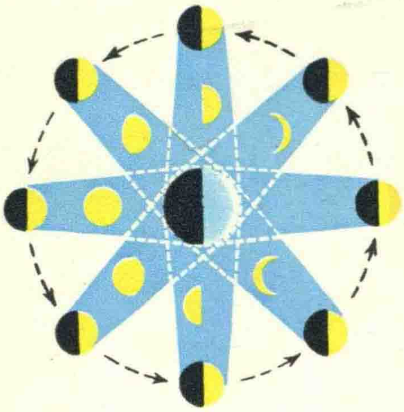


One half of the earth is illuminated by the sun while the rest is in darkness. The spinning of the earth on its axis, once every 24 hours, produces day and night.

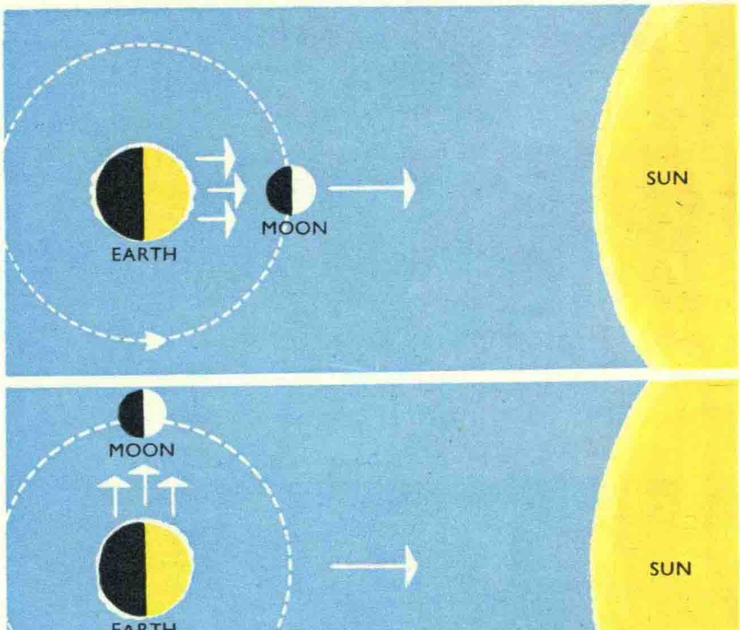


The earth takes about $365\frac{1}{4}$ days to complete its orbit round the sun. The four positions shown are the equinoxes and the solstices. The earth's axis tilts at a constant angle of $66\frac{1}{2}^\circ$ to the line of its path round the sun. This means that at the solstices one hemisphere is nearer to the sun than the other, and accepts the rays at a more oblique angle. At one end of the orbit the northern hemisphere receives its maximum warmth (Summer), and the southern hemisphere its minimum warmth (Winter), and *vice versa*. Spring and Autumn are experienced at the equinoxes.

A great many of our measurements of time have been derived from the rhythms of the movements of Earth, Sun and Moon. The spin of the earth on its axis (running from the North to the South Pole) takes twenty-four hours to complete. This can be calculated from noon, when the sun reaches its highest point in the sky (*i.e.*, when a certain part of the earth faces the sun). The 0° line of longitude through Greenwich, England, is taken as a starting point for noon, places to the west having time in advance of this, to the east behind it. A series of time zones has been created round the world roughly corresponding to the lines of longitude, and each one covering fifteen degrees. At the opposite side of the world from Greenwich is the International Date Line, from which day begins (*see* Glossary). As the diagrams on this page show, the seasons, months, and tides of the oceans are also very closely connected with the movements of Earth, Sun, and Moon.



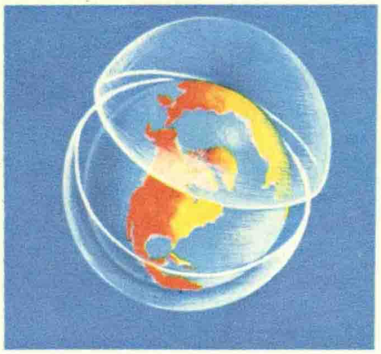
The Lunar Month. The diagram shows how we can see the moon only when we are facing away from the sun. The moon takes $27\frac{1}{4}$ days to circle the earth. When it is full, the moon is farther away from the sun than us.



The diagram shows how, once a month on its path round the earth, the moon is in an almost direct line with it and the sun. The gravitational force of sun and moon combined " pull " the water in the oceans and cause tides. The force is far less pronounced when the moon and the sun are " pulling " in different directions.

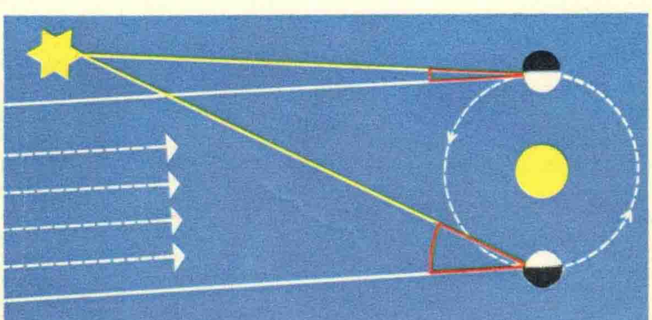
Charting the Stars

The astronomer divides the heavens into two hemispheres, north and south, corresponding to those of the earth. Using the method described below he can produce accurate star maps.

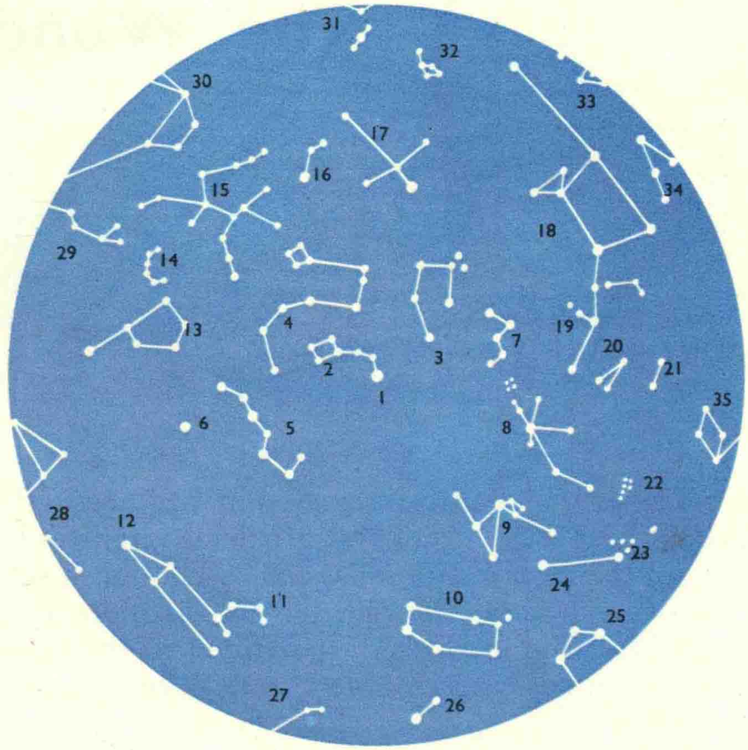


The operation of charting the stars, to make star maps recording their relative positions, is a complex one involving the taking of many observations. Briefly the method of determining a star's position is as follows. The universe is divided into two half-spheres, with the point over the North Pole as the centre of one, that over the South Pole the centre of the other. The " equator " of the universe (the outer edge of each half-sphere) follows the equator of the earth. This can be done because the axis of the earth is always pointing in the same direction (see page 132.)

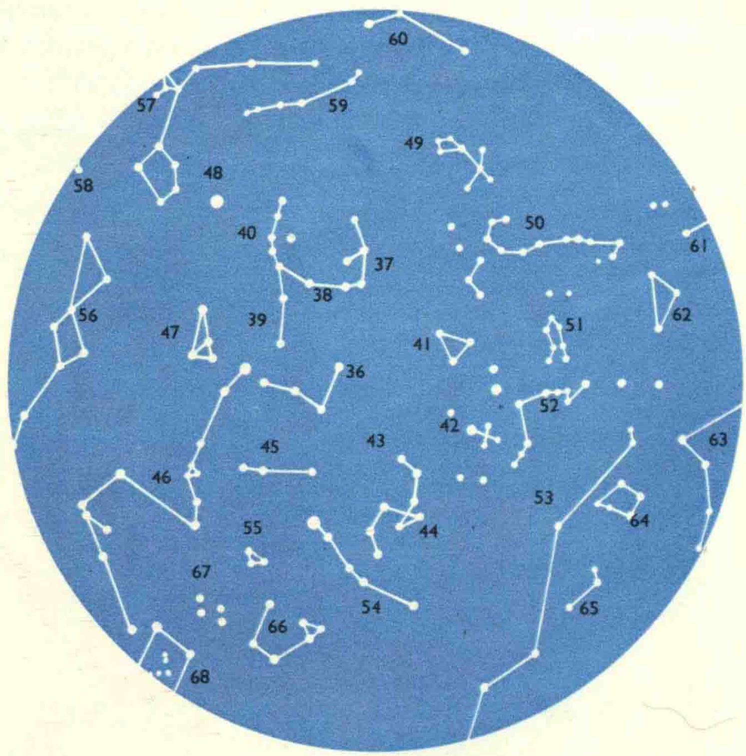
In each sphere the angle made between the star and axis of the earth can be measured, giving the " height " of the star, that is whether it is low or high in the sky. The other direction is calculated by using a fixed point in the heavens, known as the First Point of Aries. The angle at the earth between this and a star, measured anti-clockwise from the First Point of Aries, gives the " latitude " of the star, its " height " gives the " longitude" of the star.



Measuring the distance of a star. The angle to a near star will change when looked at from the opposite position, and so one can draw a triangle, and calculate the distance. This principle is called Parallax.

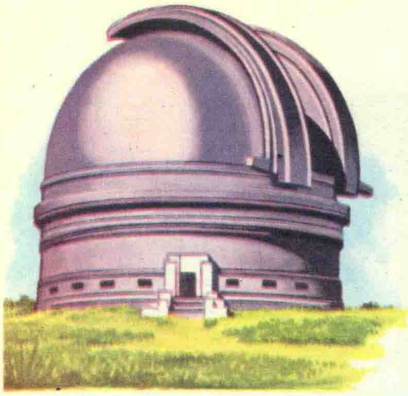


The Northern Sky. 1 Pole Star, 2 Ursa Minor, 3 Cepheus, 4 Draco, 5 Ursa Major, 6 Canes Venatici, 7 Cassiopaeia, 8 Perseus, 9 Auriga, 10 Gemini, 11 Cancer, 12 Leo, 13 Bootes, 14 Corona, 15 Hercules, 16 Lyra, 17 Sagitta, 18 Perseus, 19 Andromeda, 20 Triangulum, 21 Aries, 22 Pleiades, 23 Hyades, 24 Taurus, 25 Orion, 26 Canis Minor, 27 Hydra, 28 Virgo, 29 Serpens, 30 Ophuchus, 31 Aquila, 32 Delphinus, 33 Aquarius, 34 Pisces, 35 Cetus.



The Southern Sky. 36 Mensa, 37 Pavo, 38 Tucana, 39 Hydrus, 40 Grus, 41 Triang Aust., 42 Crux, 43 Carina, 44 False Cross, 45 Dorado, 46 Eridanus, 47; Phoenix, 48 Pisces Aust., 49 Sagittarius, 50 Scorpio, 51 Lupus, 52 Centaurus, 53 Hydra, 54 Puppis, 55 Columba, 56 Cetus, 57 Aquarius, 58 Pisces, 59 Capricornus, 60 Aquila, 61 Serpens, 62 Libra, 63 Virgo, 64 Corvus, 65 Crater, 66 Canis Major, 67 Lepus, 68 Orion.

The Wonders of the Skies

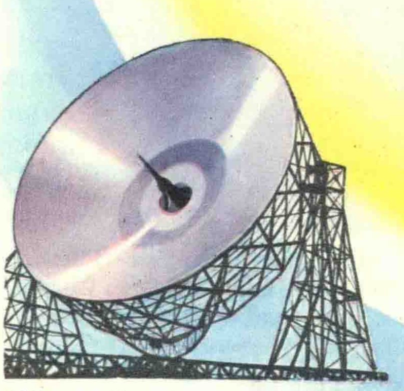


The 200-inch reflecting telescope at Mount Palomar, in California, U.S.A.

The study of the solar system has aroused great public interest in recent years because rockets and artificial satellites have been sent up from earth to begin the exploration of space. Though it seems possible that man may land on other planets, he can hardly do more than scratch at the surface of the secrets of the universe. To travel to the most distant *known* stars by rocket, at the highest imaginable speeds, would take many thousands of generations of man.

More satisfactory progress may well result from the development of new techniques of investigating space from the earth's surface or from nearby planets. Instruments like the radio-telescope at Jodrell Bank are likely to answer many questions hitherto insoluble.

Although we tend to think of the stars as always being approximately the same size, this is by no means the case. A widely held theory of the life story of a star about the size and brightness of our sun is pictured on this page. Since the sequence takes many millions of years to complete, such a theory is difficult, if not impossible, to prove. It has been arrived at by count of stars, in various stages of evolution, which can be seen today.



The radio-telescope built for the University of Manchester at Jodrell Bank, Cheshire.

Glossary

Atmosphere A layer of gases around a star or planet. In the case of the earth this is divided into three main layers, the troposphere (0 to about 10 miles), the stratosphere (10 to 50 miles), the ionosphere (50 to 300 miles).
These figures are only approximate.

Asteroid A minor planet.

Astronomical Unit This is used in making measurements between stars and planets. It is the distance between the sun and the earth, taken on average (93 million miles).

Aurora Borealis and Aurora Australis Displays of light in the sky above the polar regions, due to electrical disturbances in the ionosphere. Borealis (Arctic). Australis (Antarctic)

Binary stars A pair of stars which move round each other, held together by gravitational forces.

Celestial sphere This is used in star maps. It is an imaginary sphere around the earth divided into two hemispheres about our equator. The celestial poles are directly in line with the earth's axis.

Comet A comet is a small body moving round the sun. It appears to have a long incandescent tail pointing away from the sun.

Constellation A number of stars which make up a well defined group.

Eclipse This occurs when a body intervenes and shuts off the light of the sun from a planet. In an eclipse of the moon the earth cuts off the sun's light to the moon. In an eclipse of the sun the sun's rays are cut off by the moon so that the earth is in shadow.

Ecliptic The path of the sun as seen from the earth against the background of stars.

Equator The line of latitude midway between the North and South poles. It divides the earth into hemispheres, North and South.

Equinox The two points at which the sun crosses the equator, and when the hours of daylight and darkness are approximately equal all over the earth.

First Point of Aries The point on the celestial equator used for calculating the lines of the latitude in the celestial sphere.

Galaxy A star system.

Greenwich Mean Time G.M.T. is based on noon, when the sun is at its highest point in the sky over the 0° line of longitude which runs through Greenwich, England.

Latitude, Lines of A series of imaginary lines running parallel to the equator, each line being described by the angle which a line from a point on the earth's surface to the earth's centre makes with a line from the equator to the earth's centre.

Longitude, Lines of A series of imaginary lines running between the North and South Poles, which are used in conjunction with lines of latitude to help to place any point on the earth's surface. (See page 134.) Lines are measured taking Greenwich, England as 0°.

Lunar Month The time taken by the moon to circle the earth.

Magnitude A method of describing the brightness of a star numerically. Stars of the first magnitude are the brightest in the sky. Sixth magnitude stars can only just be distinguished with the naked eye.

Meteor A small fragment of matter which will normally be burnt up when it enters the earth's atmosphere. We then call it a shooting star.

Meteorite A meteor which is large enough to reach the earth's surface.

Midnight Sun occurs in Polar regions where sun shines for nearly six months without setting, due to the tilt of the earth's axis at an angle to its path round the sun (see page 134).

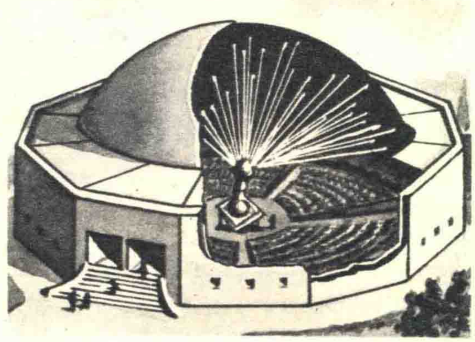
Milky Way This is seen as a band of light stretching across the heavens. It is, in fact, made up of thousands of stars.

Nebula A nebula is seen as a patch of faint white light in the heavens. The cause may be a galaxy, such as the Milky Way, or merely areas of luminous gases.

Orbit The path of one body moving round another (e.g., the earth round the sun. The moon round the earth).

Parallax The apparent change in position of a star when viewed from two points on the earth's orbit. It is used as a method of measuring the distance of a star from the earth by simple trigonometry (see page 135).

Planet A body in the solar system which circles the sun and which takes its heat and light from it.



View of a planetarium showing how the stars are projected on to the screen.

Planetarium Apparatus used to demonstrate how the stars appear in the sky at various times. A complicated arrangement of lenses and mirrors worked by electric motors throw the 'stars', moving lights, on to a silvered concave screen.

Plough The best known constellation of stars in the northern hemisphere, it appears in the sky shaped like a primitive plough, with the 'handle' pointing towards the Pole Star.

Pole Star. This star is seen directly over the north celestial Pole, and is used by navigators to find the direction of true north.

Poles of the Earth These are situated at either end of the earth's spinning axis, north and south.

Satellite A moon which circles a planet or star. An artificial satellite is a man-made object, usually containing research instruments, which circles in the same way, having been fired from earth by rocket.

Sidereal day The period taken by the earth to revolve on its axis, compared with the stars. It is four minutes shorter than the solar day, the spin compared with the sun.

Sidereal time The time based on the sidereal day. It can be calculated on Greenwich (Greenwich Sidereal Time) in the same way as G.M.T. It is the time measurement most used by astronomers in calculations, since it is more accurate than solar time.

Solar time Time based on the earth's spin in relation to the sun (24 hours). It is the time normally used in everyday work.

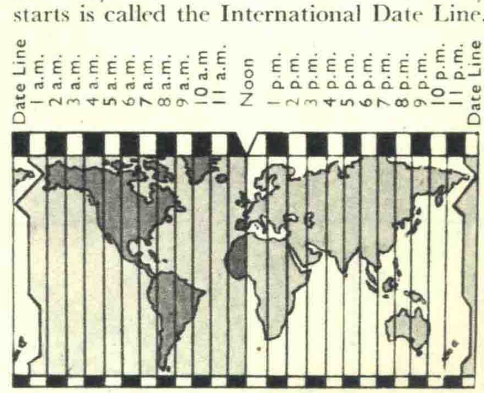
Solstices Points on the earth's orbit when the sun is seen at its most northerly or most southerly in the sky. They occur on 22 December and 22 June each year (see page 134).

Southern Cross A group of stars near the south celestial pole which can be used to mark the pole itself. There is no really bright star at the south celestial pole, but by continual observation of the Southern Cross which circles it, it can easily be pin-pointed.

Sunspots These are patches on the sun's surface which appear from time to time, but especially in a cycle every eleven years. One of the reasons for their importance is that they enable the spin of the sun to be calculated. Their cause is not certain, but it is probable that when they occur the sun's heat is greater than usual. Sunspots are cooler than the surroundings, and are known to be the centres of magnetic fields.

Synodic Period. The interval between the occasions when any two planets are in line with the sun. The faster moving planet will, after a complete revolution, catch up with the slower. It is useful in calculating the length of a planet's "year".

Time zones Since the spin of the earth takes 24 hours, it follows that places around it experience noon at different times (see page 134). For convenience the earth is divided into 24 time zones, covering 15° of longitude. Countries covering more than one of these time zones usually have one standard time. Briefly, time zones to the east of Greenwich have time in advance of it (1 hour for each zone), while those to the west have time behind it. As noon at Greenwich (0° longitude) countries at the other side of the world (180° longitude) are experiencing midnight, and the start of a new day. The line from which the day starts is called the International Date Line.



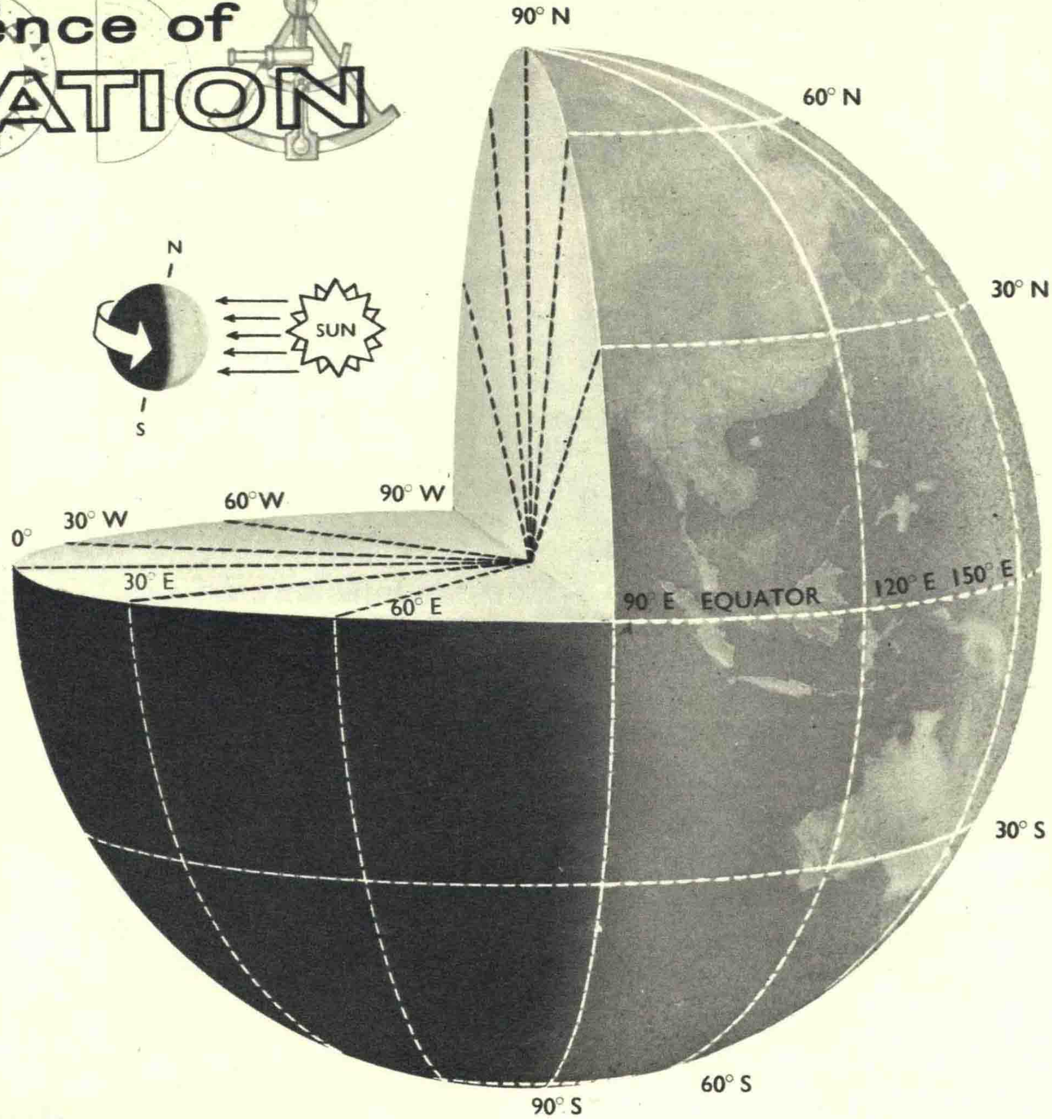
The time zones of the world.

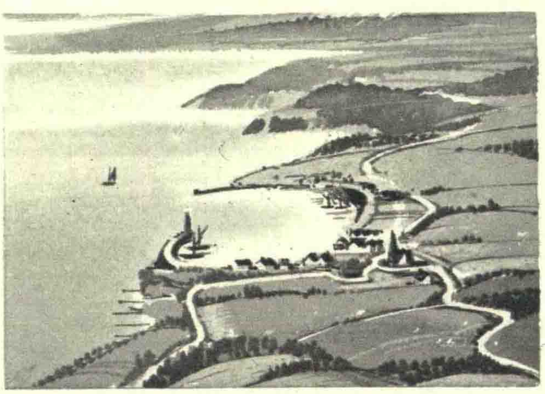
Variable stars The brightness of the light from these stars varies from time to time. This may be caused by changes within the stars or by intermediate stars eclipsing them.

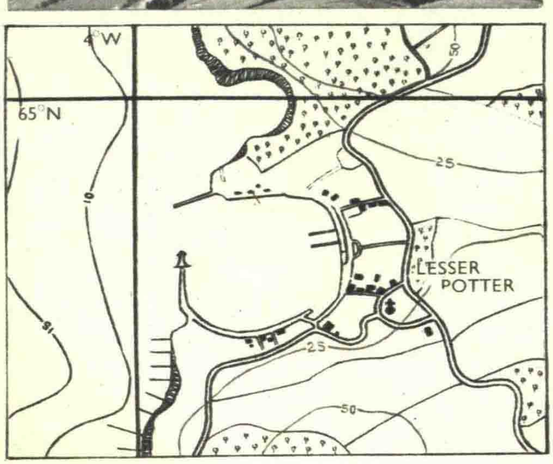
Zenith The point on the celestial sphere which is directly overhead.

The Science of NAVIGATION

For convenience the navigator divides the globe of the earth into areas bounded by lines of latitude and longitude. Reference to these lines enables him to pinpoint exactly any spot on the earth's surface. Lines of longitude run from the North to the South Poles; lines of latitude run from east to west, parallel to the Equator. The diagram on the right shows how the lines make an angle at the centre of the earth. Lines of latitude are measured by the angle they make at the centre of the earth with lines from there to the Equator (e.g., 30°N., 45°S.). The Equator is 0°, measured either way. Lines of longitude are measured by their angle east or west from the line joining the Poles along the earth's surface through Greenwich, England (0°). Thus they are given as 80°E., 120°W., and so on. The line on the opposite side of the world from 0° is 180°, measured either way (since there are 360° in the full circle).





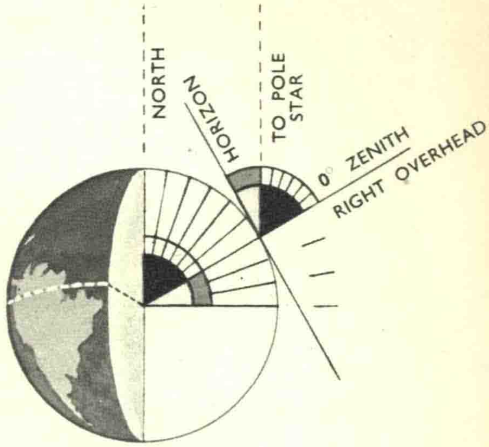


The navigator's job is to find out and check his position with reference to his surroundings. He must be able to say with great accuracy exactly where he is on the earth's surface.

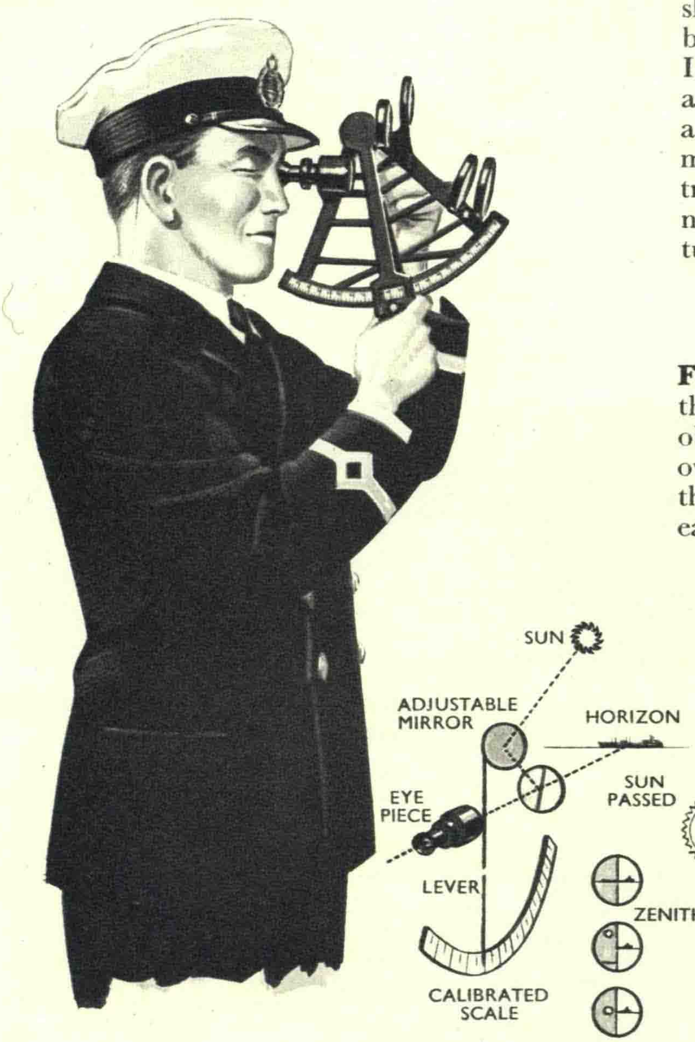
Perhaps the first thing the navigator needs is a good map. The map is a plan of a part of the earth, set down to scale. The main features usually incorporated in the map are lines of latitude and longitude (see above), the coast lines of land masses, the depths of the sea, the height of the land, and points of especial interest or importance, such as rocks, light-ships and prominent buildings. The way in which land heights and ocean depths are shown is as follows. All points of the same height on the map are joined by *contour lines*, given in feet above sea-level or in the case of ocean depths, usually in fathoms below sea-level. A fathom is equal to six feet. The seaman's maps and charts, of course, give him information which he will especially require, whereas the land maps, such as those made by the Ordnance Survey Department, will probably give a rather different selection, designed for other purposes. The coastal scene and map on the left show how they compare.

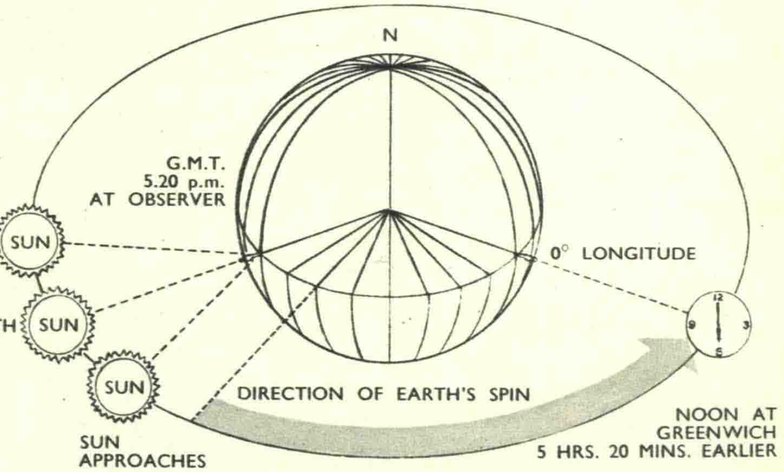
Checking Position

Finding Latitude The blackened-in angles must be equal, because they are made by a line cutting two parallels. With each of the shaded angles added they become right angles (90°). It follows that the shaded angles are also equal. The angle above the horizon made by the Pole Star subtracted from 90° gives the number of degrees of latitude.



Finding Longitude The earth takes 24 hours to revolve through its 360° of latitude. By taking a comparatively stable object in the sky (the sun), and checking the time it arrives overhead, i.e., at its highest point, the angle through which the earth has spun from 0° at noon, Greenwich Mean Time is easily calculated (360° ÷ 24 (hours) = 15° each hour).

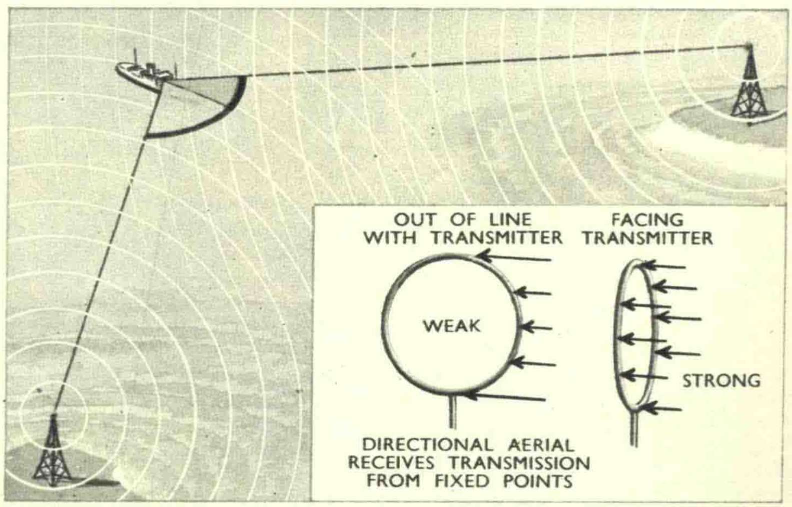




OBSERVER'S LINE OF LONGITUDE IS 80° W

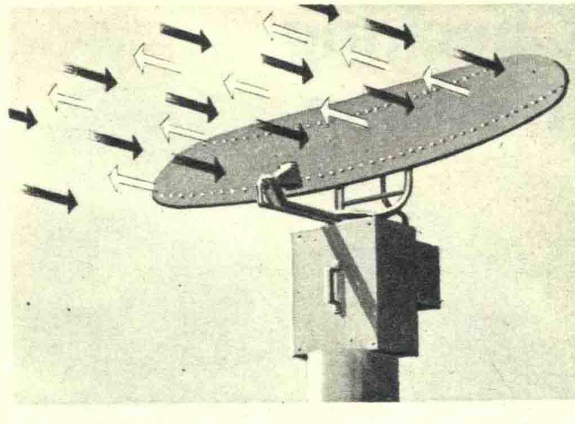
Using a sextant, as with a periscope, the image is seen reflected through two mirrors. 0° elevation is established by looking straight through the eye piece to the horizon. The angle of elevation to the sun is worked out by moving the upper mirror until the sun can be seen, and checking the lever which moves it against a calibrated scale.

To check his position when he is out of sight of land, the navigator can take advantage of the sun and stars to make his calculations. The heavenly bodies may be used to find an exact reference in terms of latitude and longitude, as described above. In using his sextant to measure the angles of the stars, the navigator must ensure that he makes allowance for the distance, if any, he is standing above sea-level. An error of a few feet will make a considerable difference to the final calculations, for the angles measured will be affected.



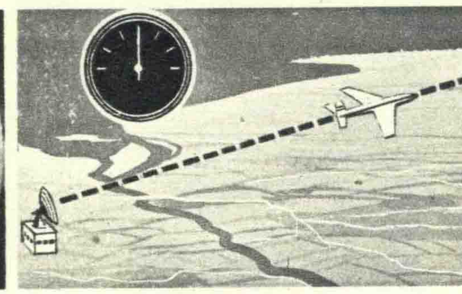
Ships can calculate their positions by using radio signals directed from two or more fixed transmitters, whose positions are known. A directional aerial on the ship enables a bearing to be taken to each transmitter. The point where these bearings cross when plotted on a map is the position of the ship.

Radar is being used increasingly in the navigation of both ships and aeroplanes. Radar is not hindered when visibility is poor, either by darkness or by fog. It uses a directional radio beam, either fixed or rotating. It may be compared with a searchlight, for waves are reflected back to the source from any objects in the vicinity. The longer they take to return (measured in tiny fractions of a second) the farther away the objects are known to be. The returning waves are fed into an apparatus which pictures their path on a screen, giving an accurate representation of the scene around. Ships, land, and other solid objects show up as white spots. A scale is marked on the screen to show the relative distances of objects from the radar screen.



The radar aerial on board ship both transmits and receives waves which have 'echoed' back. It revolves slowly on its axis so that all directions are scanned.

1. Four ships in convoy in bad visibility near land. 2. The centre ship sends out radar beams, which are reflected back from nearby objects. 3. The ship's radar screen shows up surrounding ships and land in white, with the distances compared against a fixed scale.



An aeroplane flies along a fixed directional radar beam. A dial (inset) indicates if the plane is deflected from course.

Glossary

Altitude Height, especially of an aircraft, usually expressed in feet.

Bearing Clockwise angle made at the point of observation between true north and another point in the distance. It is recorded by compass and, when plotted on a map, used to determine position. A back bearing is the angle between true north and the observer, made at the object observed.

Celestial Navigation Navigation using the stars and other heavenly bodies as points of reference.

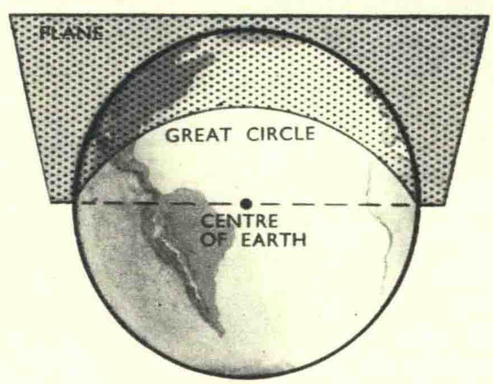
Charts, Navigational Maps which include detailed information on ocean depths, coasts, rivers, harbours, lighthouses, buoys, etc.

Coastal Navigation Navigation near to land is conducted in good visibility by reference to points on or near the coast, and whose positions are known. Bearings are taken to these points to establish the exact position of the ship or aircraft.

Contour Lines Lines plotted on a map joining points of equal height or ocean depth.

Equator Line of latitude equidistant from the north and south geographic poles.

Great Circle The shortest route between two points on the earth's surface. It may be described as the line on the earth's surface made by a plane cutting through to the centre of the earth. Plotted on most maps the line of a Great Circle appears as a curve, because of the distortion of the map projection.



The line of a Great Circle

Greenwich Mean Time See page 137.

Inertial Navigation A method of keeping track of one's position without observation of outside objects. It uses the principle of inertia (see page 216), and sensitive instruments within the aircraft or submarine can record exactly how far it has travelled and in what direction since leaving port.

North and South Geographic Poles See page 137.

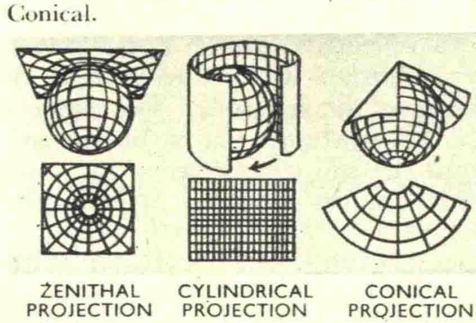
Gyro Compass In this instrument the axis of a freely spinning wheel is forced electrically to point in the direction of True North. Once this is done, the gyro will maintain itself in this position. It is an extremely accurate form of compass and is not subject to variation or deviation.

Knot A speed of one nautical mile (6,080 feet) per hour.

Latitude See page 138.

Longitude See page 138.

Map A plan view of the earth's surface. Since it is not possible to reproduce the curved surface on a flat plane, various " projections " or mathematical distortions have to be used, and allowances are made for these when reading the map. The main projections in use are Zenithal, Cylindrical, and Conical.



Nautical Measurement The following is the table of units of length used at sea:—

6 feet	=	1 fathom
100 fathoms	=	1 cable
10 cables	=	1 nautical mile

Parallel Sailing Sailing round a line of latitude.

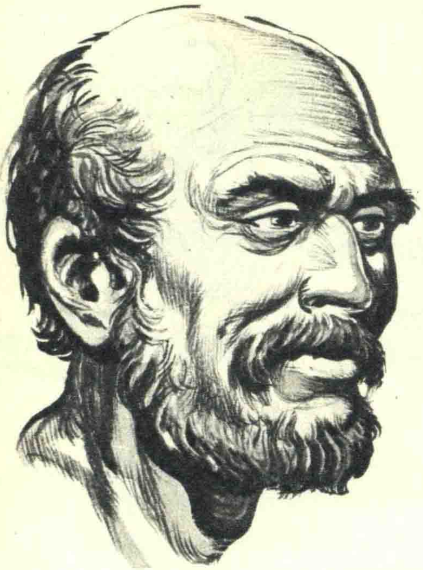
Port The left side of a ship seen when facing forward.

Starboard The right hand side of a ship seen when facing forward.

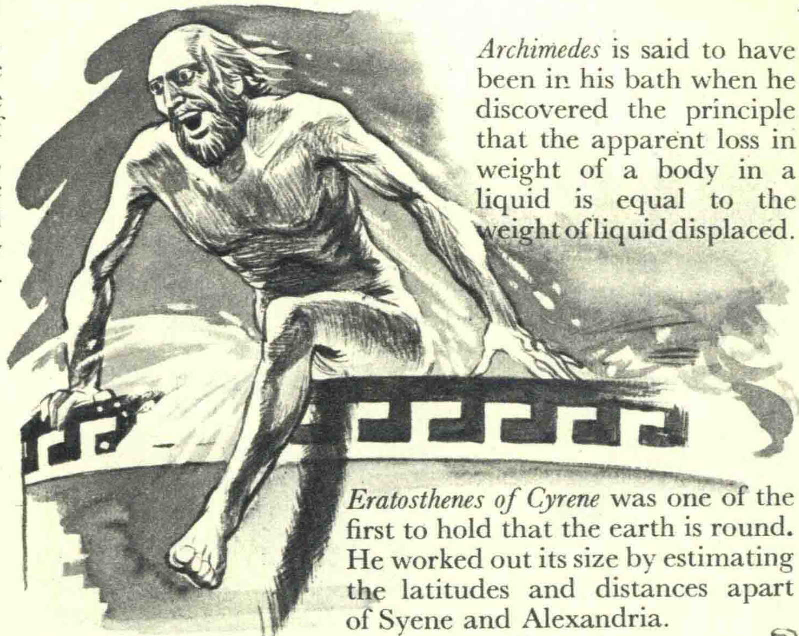
Telescope See page 123.

Tropics of Cancer and Capricorn Lines of latitude 23° 28° north and south of the equator respectively, where the sun appears to turn after reaching its highest point north or south.

FAMOUS MEN OF SCIENCE



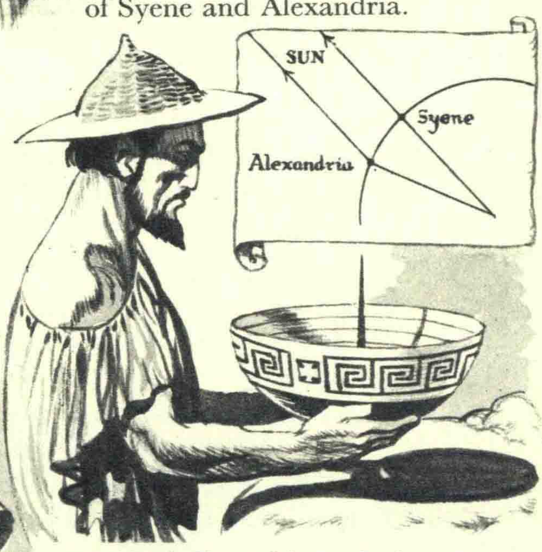
The Greek thinker, *Democritus* first wrote of the idea that the universe is made up of " indivisible " atoms, so minute as to be invisible to the naked eye. The theory, now accepted, had little influence at the time.

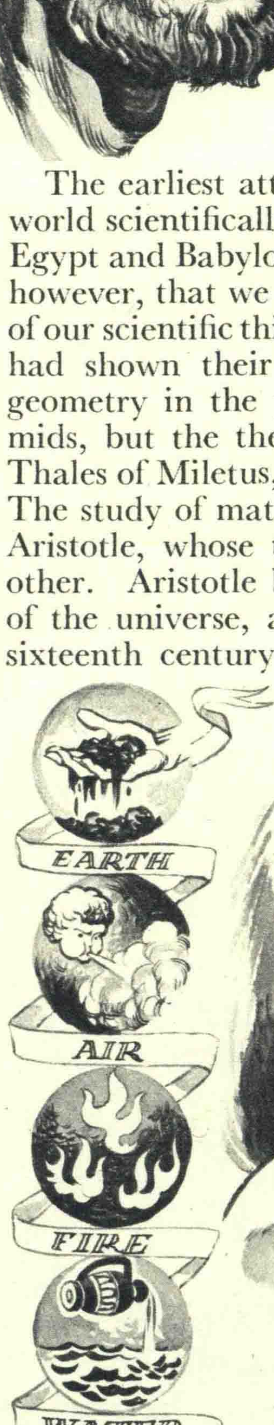


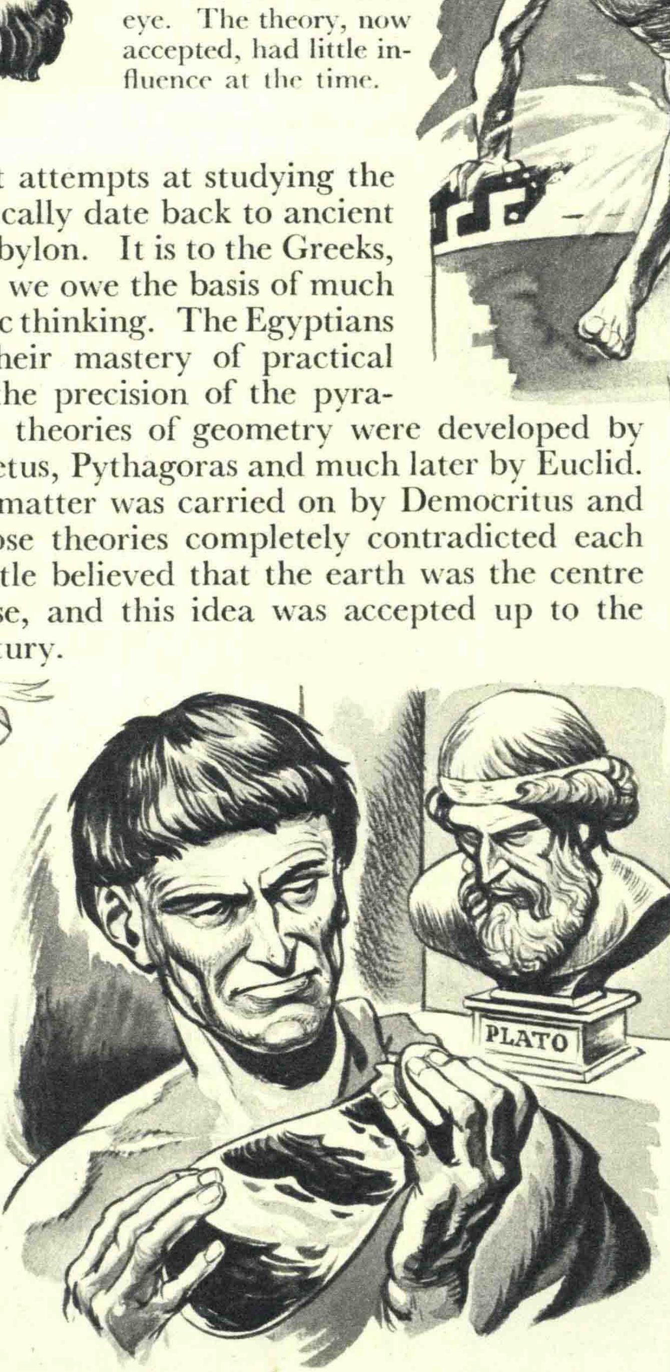
Archimedes is said to have been in his bath when he discovered the principle that the apparent loss in weight of a body in a liquid is equal to the weight of liquid displaced.

The earliest attempts at studying the world scientifically date back to ancient Egypt and Babylon. It is to the Greeks, however, that we owe the basis of much of our scientific thinking. The Egyptians had shown their mastery of practical geometry in the precision of the pyramids, but the theories of geometry were developed by Thales of Miletus, Pythagoras and much later by Euclid. The study of matter was carried on by Democritus and Aristotle, whose theories completely contradicted each other. Aristotle believed that the earth was the centre of the universe, and this idea was accepted up to the sixteenth century.

Eratosthenes of Cyrene was one of the first to hold that the earth is round. He worked out its size by estimating the latitudes and distances apart of Syene and Alexandria.



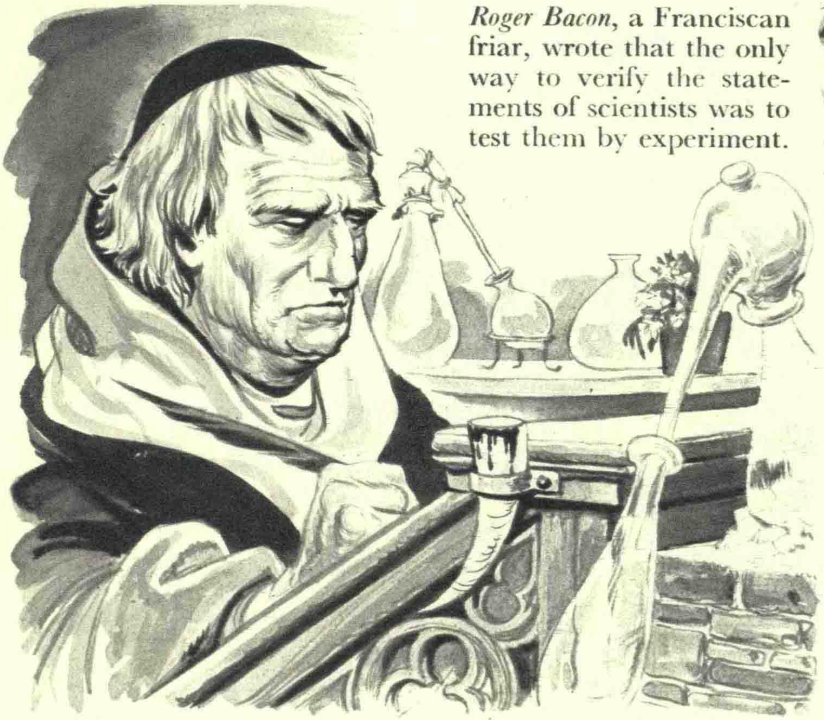




Aristotle, one of the leading figures in Greek science, and a pupil of the philosopher *Plato*, believed that all matter was made up of four elements; earth, air, fire and water. He is said to have demonstrated this by shaking together four liquids that would not mix in a flask. This mistaken idea dominated the science of chemistry for hundreds of years, until Dalton in the nineteenth century showed it to be incorrect.

Euclid of Alexandria took the geometric science of *Thales* and *Pythagoras* and formulated the set of theorems into the books which bear his name.

The Dark Ages

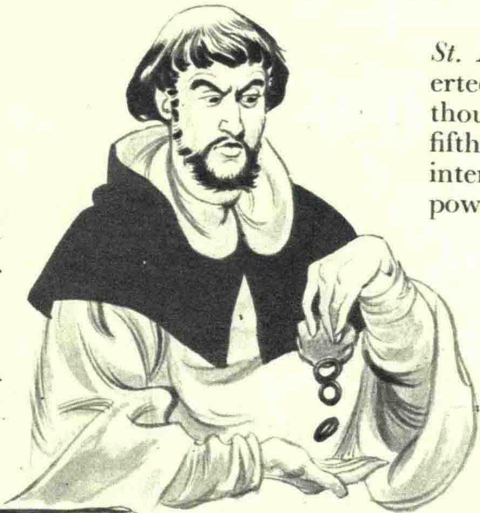


Roger Bacon, a Franciscan friar, wrote that the only way to verify the statements of scientists was to test them by experiment.

Hero of Alexandria was one of the first experimenters, but many of his ideas were not true science. Many of his " tricks " involved the use of fire and steam, as does this simple reaction turbine.

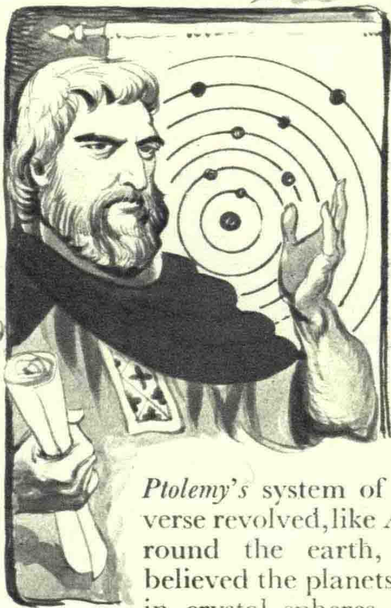
Scientific thinking during the early Middle Ages was strongly influenced by Greek and Arabic science. Chemistry had gained importance, mainly being carried on by the Alchemists in their search for the "philosophers' stone," which they believed possessed the power to turn base metals into gold. The Arabian alchemist Geber gave descriptions of refining metals, dyeing cloths, and preparing many chemical compounds. Astronomy was still largely dominated by the theories of Aristotle, but was decorated by Ptolemy's idea that surrounding the earth was a set of revolving crystal spheres in which the sun and stars were embedded.

The centuries succeeding the Norman Conquest produced three great scientists all of whom were in holy orders. They were Roger Bacon, Albertus Magnus, and Thomas Aquinas. They based their ideas on classical theories, but stressed the need to perform more extensive experiments in order to obtain accurate results.

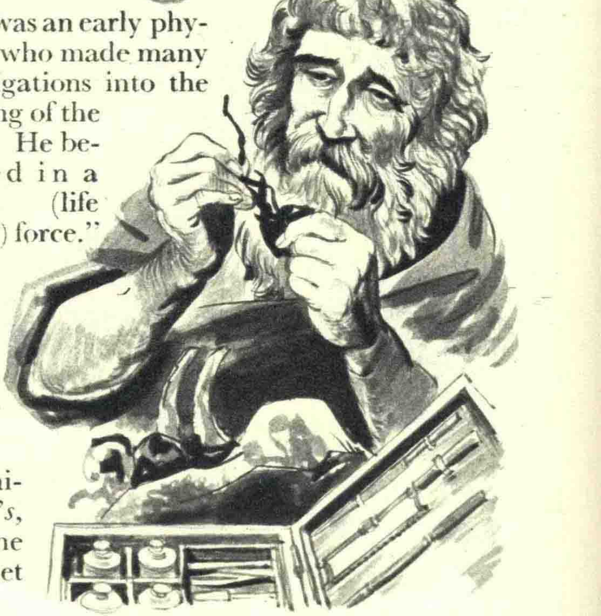


St. Augustine of Hippo exerted great influence over thought in the fourth and fifth centuries. He was interested in the magnetic powers of lodestone.

Geber, the most famous of Arabic chemists, lived in the 8th century. He described the preparation of steel, nitric acid, lead carbonate and many chemical compounds.



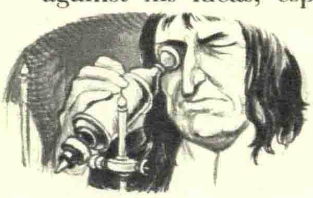
Ptolemy's system of the universe revolved, like *Aristotle's*, round the earth, but he believed the planets were set in crystal spheres.



Galen was an early physician who made many investigations into the working of the body. He believed in a "vital (life giving) force."

The First Experimenters

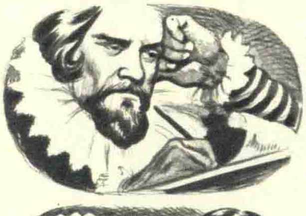
Copernicus, the 16th century Polish astronomer, first showed that the sun was the centre of the planetary system. Before this most men had believed that the earth was stationary and probably flat. Copernicus had to face tremendous opposition against his ideas, especially from the Church.



Robert Hooke had wide interests in science and his work included the study of animal and vegetable structures, magnetism, air pressure, and astronomy.

Robert Boyle found that the pressure and volume of a gas are inversely proportional (Boyle's Law). He carried out important experiments on combustion.

Johannes Kepler, a great mathematician and astronomer, was able to expand Copernicus' theory of the solar system, with the help of *Tycho Brahe*.

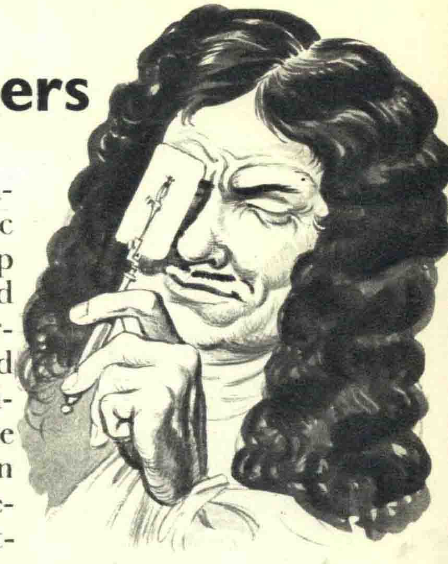


Francis Bacon, an influential writer and a Lord Chancellor of England, stressed the need for experiment in science, arguing from the facts to the theory (inductive logic).

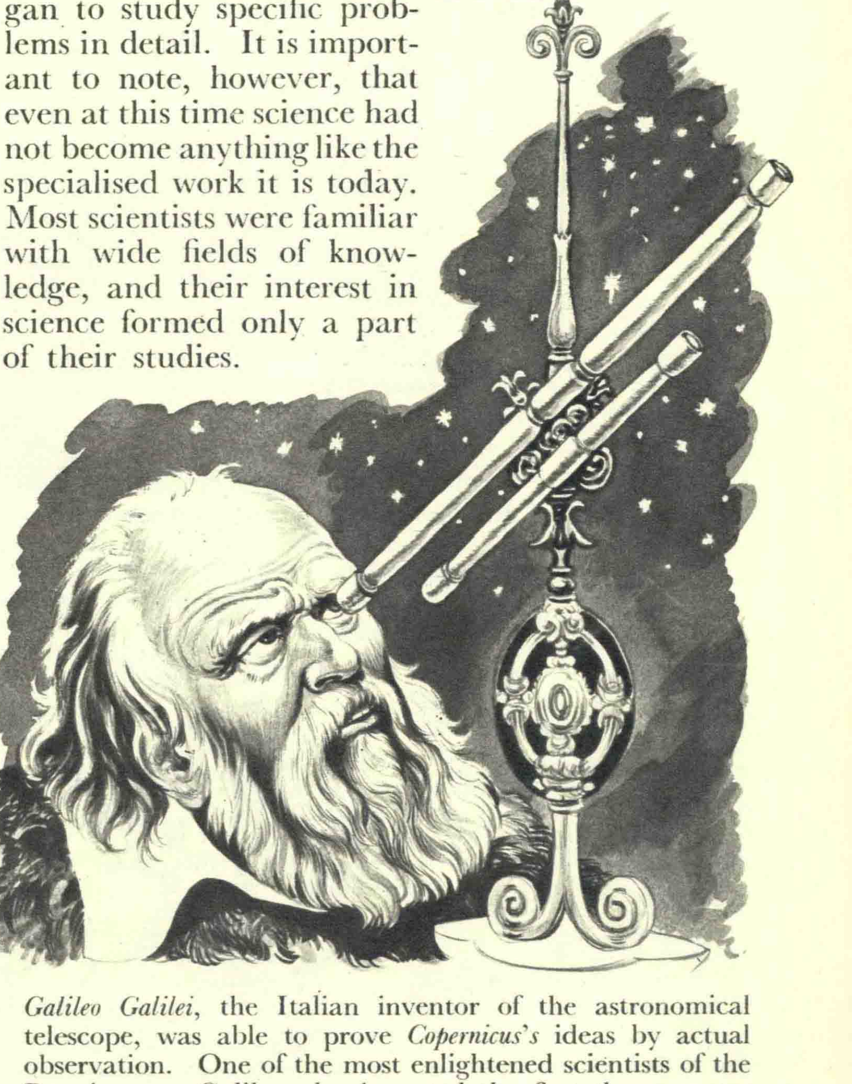
Otto von Guericke made the first air pump and demonstrated air pressure by an experiment in which teams of horses tried to pull apart two metal hemispheres containing a vacuum.

William Gilbert experimented with magnetism and calculated the magnetic dip of a compass needle and introduced the important idea that the earth is a magnet.

With the re-birth of learning in Europe, scientific studies began to develop rapidly, and many of the old misconceptions were overthrown. Copernicus and Galileo made great contributions to astronomy, the former showing that the sun was the centre of the planetary system, the latter inventing the astronomical telescope. The learned Francis Bacon strongly urged the need to base arguments on facts proved by experiment and many investigators began to study specific problems in detail. It is important to note, however, that even at this time science had not become anything like the specialised work it is today. Most scientists were familiar with wide fields of knowledge, and their interest in science formed only a part of their studies.



The invention of the simple microscope by *Antony van Leeuwenhoek* was a landmark. The combination of lenses allowed far closer examination of plant and animal structure.

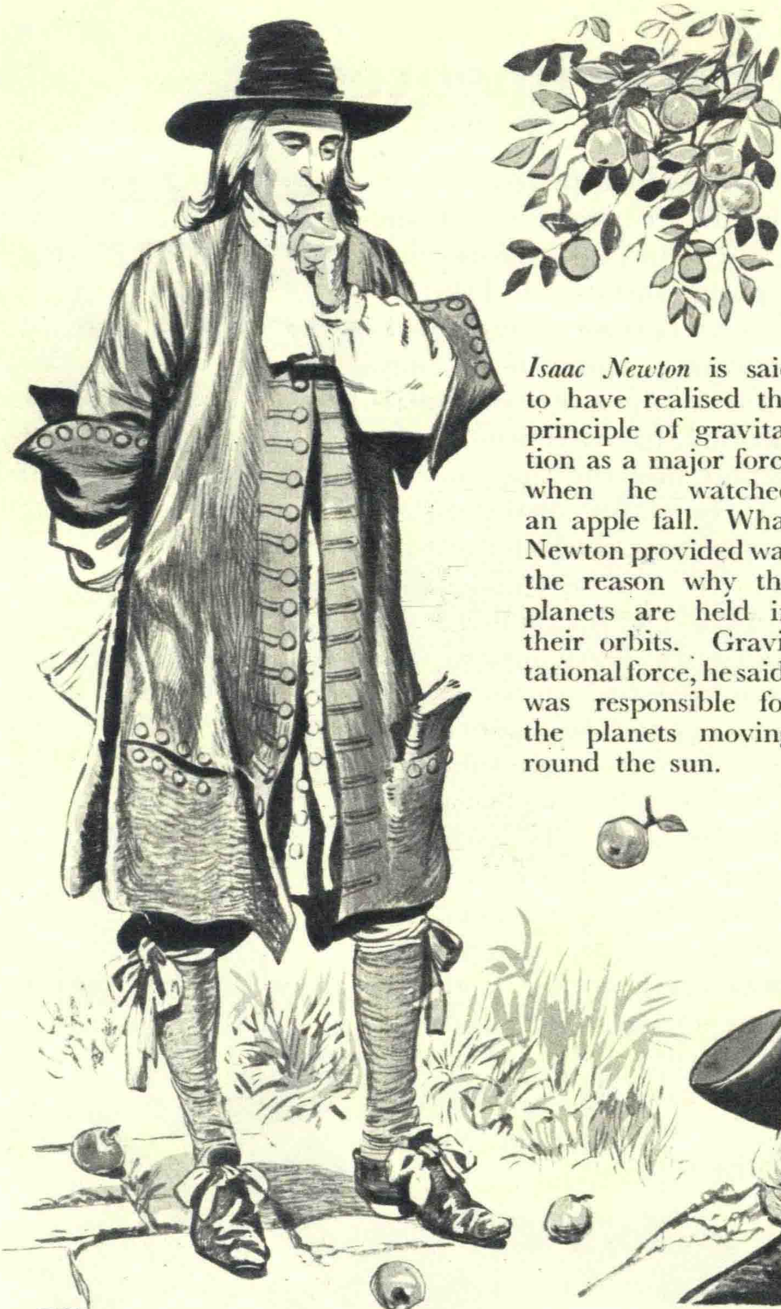


Galileo Galilei, the Italian inventor of the astronomical telescope, was able to prove *Copernicus's* ideas by actual observation. One of the most enlightened scientists of the Renaissance, Galileo also invented the first thermometer and founded the science of dynamics, the study of the way bodies behave under the action of forces.

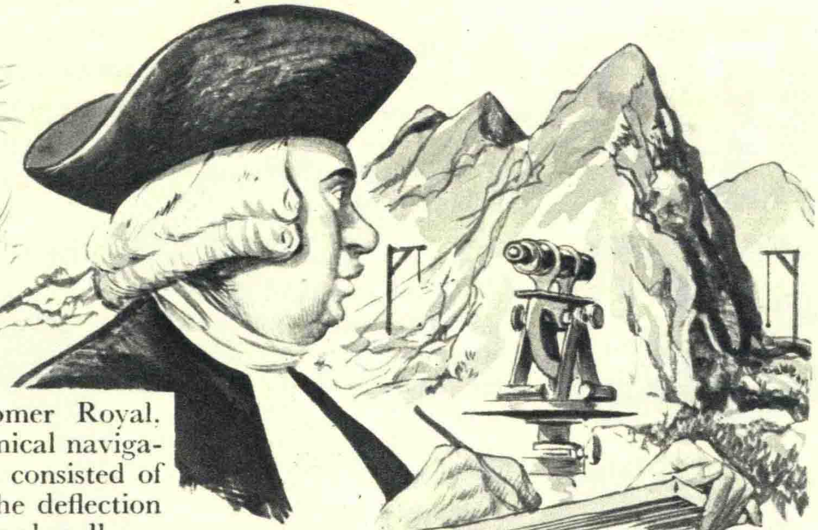
The Universe

The tempo of scientific interest began to speed up enormously towards the end of the seventeenth century. Newton's formulation of the laws of gravity revolutionised many of the ideas about the universe. The study of the nature of the earth itself—geology, geography, meteorology and the physics of light—became increasingly important. Theories of how the earth came into being, so long the province of the Church, became the subject of much (sometimes wild) speculation. It was realised that the age of the earth was far older than had been thought.

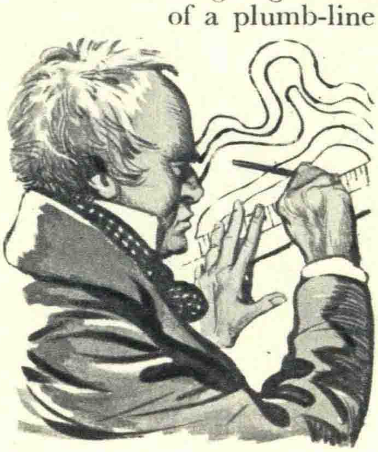
The seventeenth century saw, too, the beginnings of organised scientific discussion. Several learned bodies were set up in Europe where scientists could meet and exchange information about their discoveries. The *Royal Society* was formed in London in 1662, and had its counterparts in many European countries.



Isaac Newton is said to have realised the principle of gravitation as a major force when he watched an apple fall. What Newton provided was the reason why the planets are held in their orbits. Gravitational force, he said, was responsible for the planets moving round the sun.



Nevil Maskelyne (right), an Astronomer Royal, made many improvements in astronomical navigation. A famous experiment on land consisted of weighing a mountain by observing the deflection of a plumb-line caused by gravitational pull.



Baron von Humbolt drew the first isotherm maps and charted the Humbolt current.

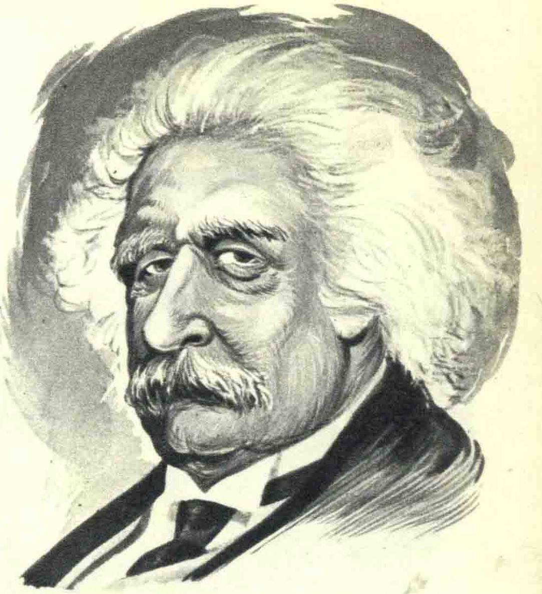
Eduard Suess, the Austrian geologist studied the formation of continents and mountains.

Sir William Herschel helped to catalogue the stars, discovered Uranus, and studied the nature of light.

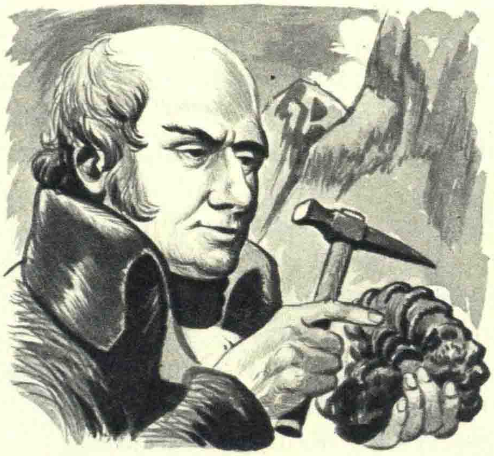
Christiaan Huygens first put forward the idea that light travels in a wave-like motion.

Yields Its Secrets

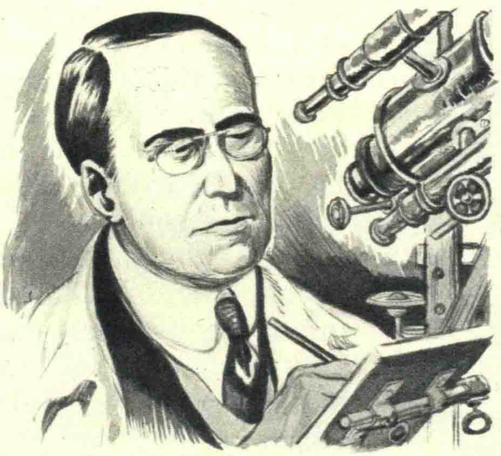
Along with the interest in the nature of the universe came the problems of man's place in it. At the beginning of the nineteenth century a French naturalist, Lamarck, had suggested that animals had evolved by the inheritance of acquired characters and the use and disuse of organs. The publication of Darwin's book *Origin of Species* in 1859 created an uproar in scientific and religious circles. In it he stated that all life had evolved over a period of hundreds of millions of years from extremely simple creatures. The fact that the teachings of these men apparently contradicted so much of the Church's teaching about the creation of the world made them the subject of many attacks until well into the twentieth century. Research into the past was the keynote of much of the scientific work in the nineteenth century. Archaeology, palaeontology and the historical study of the language groups have all flourished since that time. Another aspect of this has been the interest in genetics as studied by Mendel and later workers.



Albert Einstein, mathematician and astronomer, revolutionised ideas about gravitation. He revised Newton's laws to include the behaviour of very small bodies like atoms, and very large systems like galaxies. In his general theory of relativity he showed that time and space were inseparable.



William Smith carried on extensive studies into rocks and fossils, and produced a theory that rocks could be identified by their fossils.



Sir Stanley Eddington made many studies of the evolution of the stars, how they move, and how they are composed.

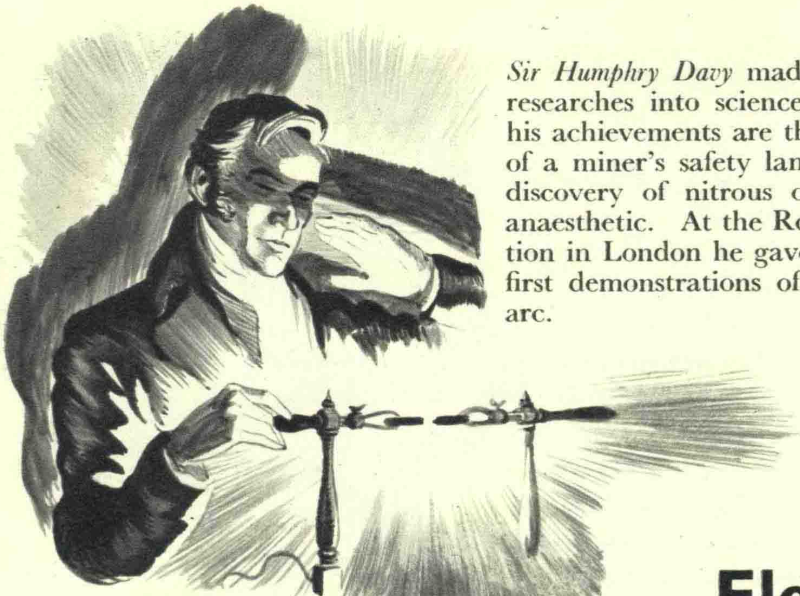
1. *Thomas Huxley* the biologist, agreed with *Darwin's* theory of evolution. He made many important studies of animals.

2. *Joseph Gay-Lussac* improved methods of chemical analysis and studied atmospheric conditions at high altitudes by making balloon ascents.

3. *Sir Charles Lyell* showed that rocks today are still being laid down and the earth's crust still being changed as in early times.

4. *Baron Cuvier* rejected the idea of continuous evolution after long study of fossils, and improved methods of classifying animals.

Charles Darwin sailed to the South Seas and to the Galapagos Islands, where, from his study of plant and animal life he became convinced that plants and animals had evolved by natural selection.

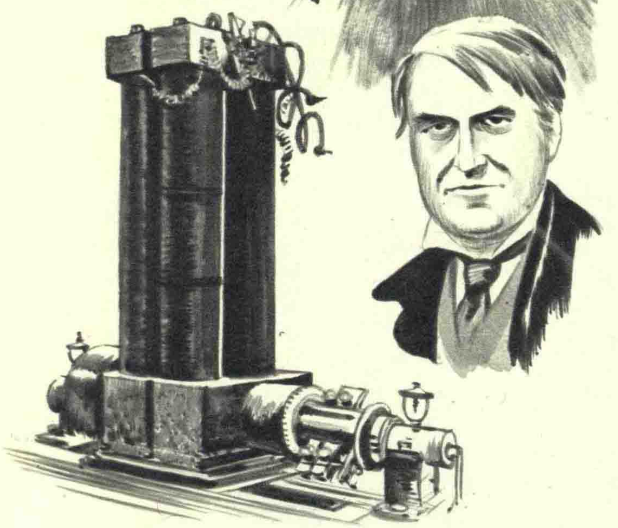


Sir Humphry Davy made numerous researches into science. Amongst his achievements are the invention of a miner's safety lamp, and the discovery of nitrous oxide as an anaesthetic. At the Royal Institution in London he gave one of the first demonstrations of an electric arc.

Heinrich Hertz detected the first electromagnetic radio waves produced by the spark from an induction coil. These are used in all broadcasting and television today.

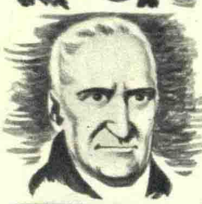
Electricity and Waves

Though static electricity had been known for hundreds of years, it was not until the end of the eighteenth century that electricity was found to be of use to man. Galvani and later Volta, both Italians, had investigated the problem, the latter inventing a battery called the Voltaic Pile. Many scientists used electric currents and examined their effects, including Oersted, Davy and Faraday. Davy discovered the metals sodium and potassium, which he isolated by passing electric current through molten salts. Oersted established the connection between magnetism and electricity, and there followed important practical results from Faraday's work with the electric motor and the dynamo. Later investigation brought about the discovery of radio waves by Heinrich Hertz in 1887 and of X-rays by Röntgen in 1895.



Thomas Alva Edison invented many electrical devices including the phonograph and the first really efficient dynamo.

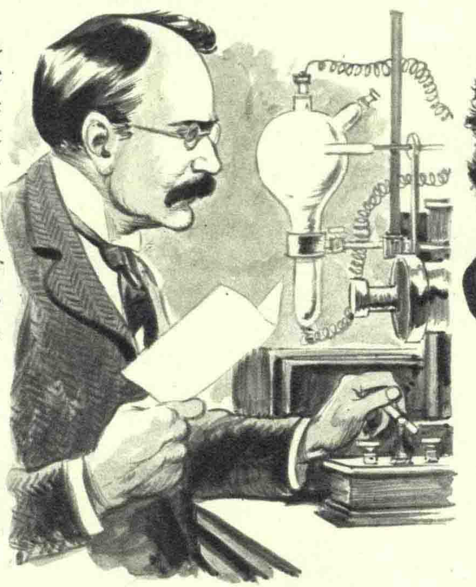
Luigi Galvani suspended a frog's leg by copper wire on an iron railing. He concluded (wrongly) that electricity was set up by the metals and the frog's legs.



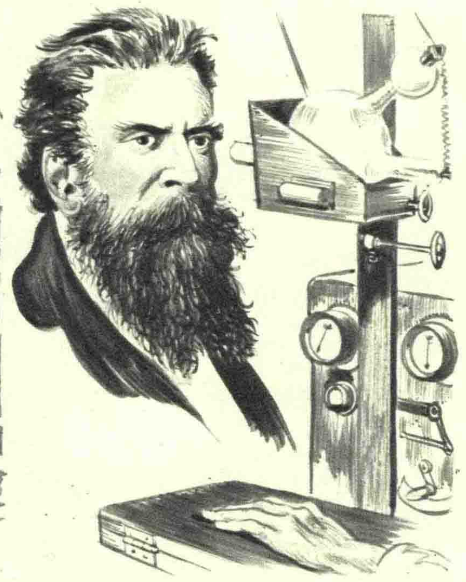
Allessandro Volta produced the first battery made of a series of zinc and copper discs placed between cards soaked in acid.

André Ampère showed that coils of wire carrying electric currents acted like magnets, thus founding the study of electro-magnetism.

George Ohm formulated the theory of Ohm's Law, stating that current equals electro-motive force divided by the resistance of wire.



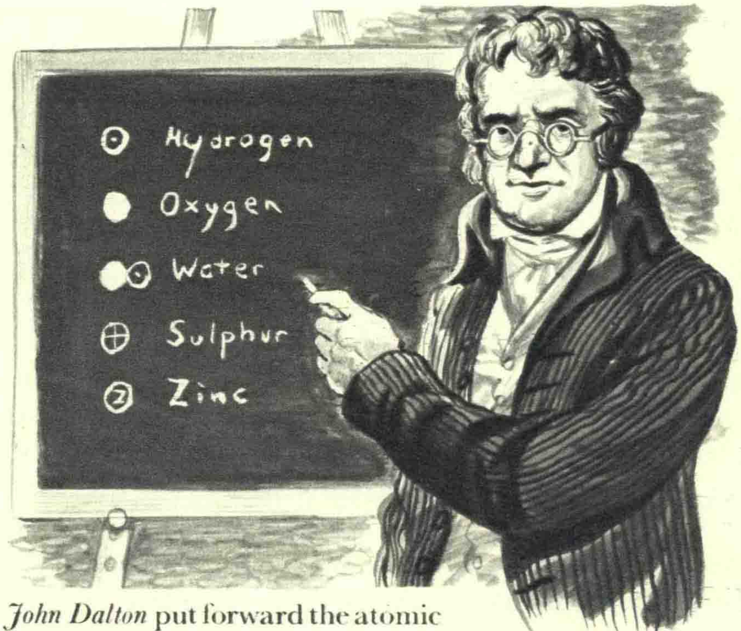
Sir Joseph Thomson was one of the men most concerned with the development and theory of cathode rays showing that they consist of a stream of very small particles shot out from the cathode.



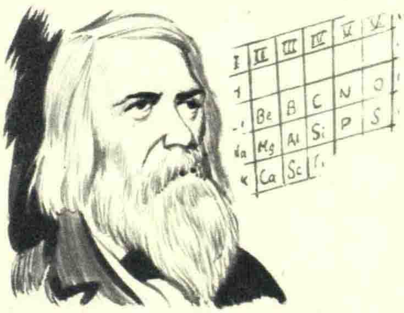
Wilhelm Röntgen discovered that crystals of barium platinocyanide glowed when an electric discharge was passed through a vacuum tube nearby. The penetrating rays which caused this he called X-rays.

The Mighty Atom

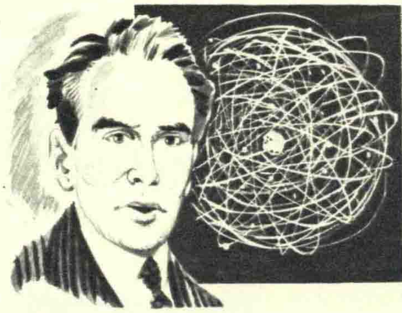
The idea that the universe is made up of atoms, although of Greek origin (see page 141), dates back in its modern form to the work of John Dalton, a chemist who studied the relative weights of elements which combine to make chemical compounds. A table of the elements, in the order of their increasing weight, was drawn up by the Russian Mendeleéf, by which it was possible to study them in groups, having related properties, and also to predict the properties of the elements not then discovered. J. J. Thomson's brilliant work on the conduction of electricity through gases led him to the discovery of the electron in 1897. Lord Rutherford investigated the atom by bombarding it with alpha-particles given out by a radio-active material and 1911 produced his theory of the atomic nucleus containing small positively charged particles which he called protons. C. T. R. Wilson invented the cloud chamber in the same year. In 1932 James Chadwick discovered the third atomic particle, the neutron.



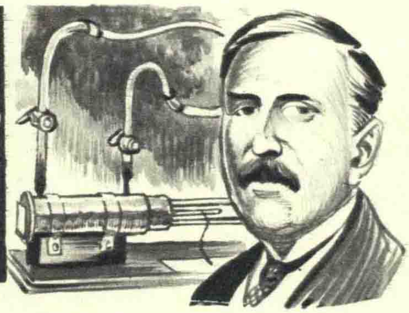
John Dalton put forward the atomic theory of matter from which modern chemistry has developed. He realised that elements consist of atoms of one type.



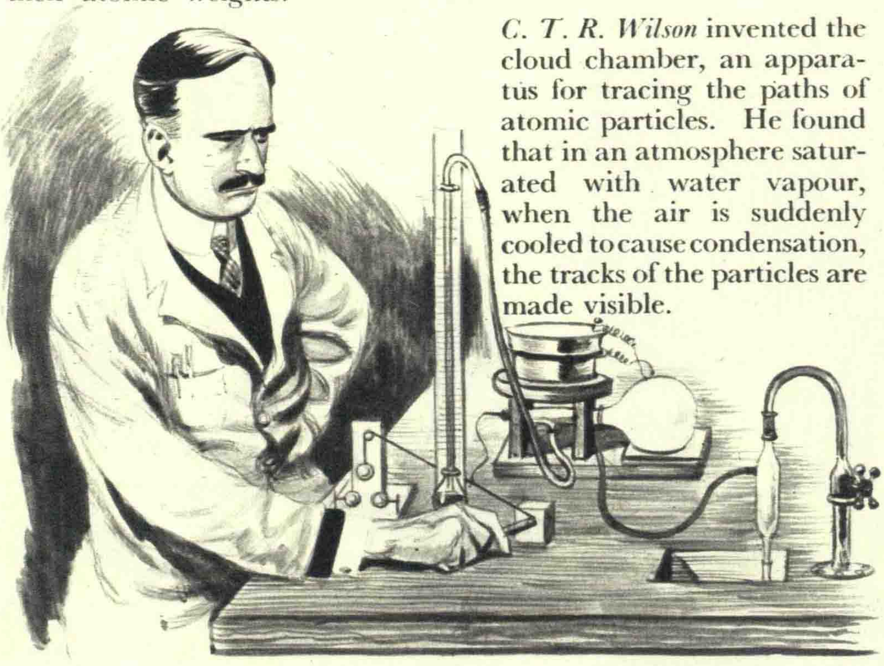
Dmitri Mendeleéf, following *Dalton*, drew up a Periodic Table of elements in order of their atomic weights.



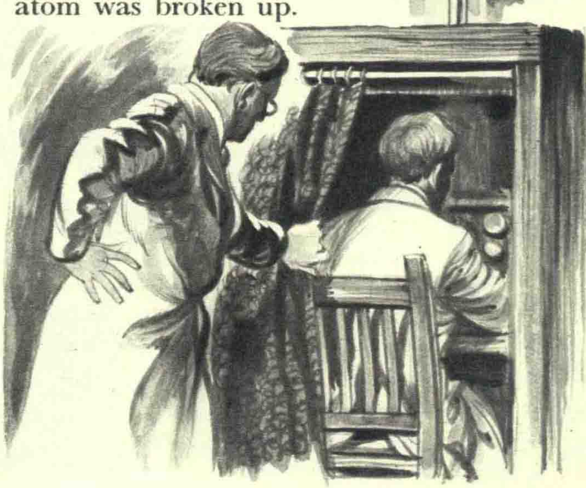
Niels Bohr applied the Quantum theory of Planck to the study of the structure of the atom.



Lord Rutherford put forward the nuclear theory of the atom, and in 1918 he became the first to split the atom.



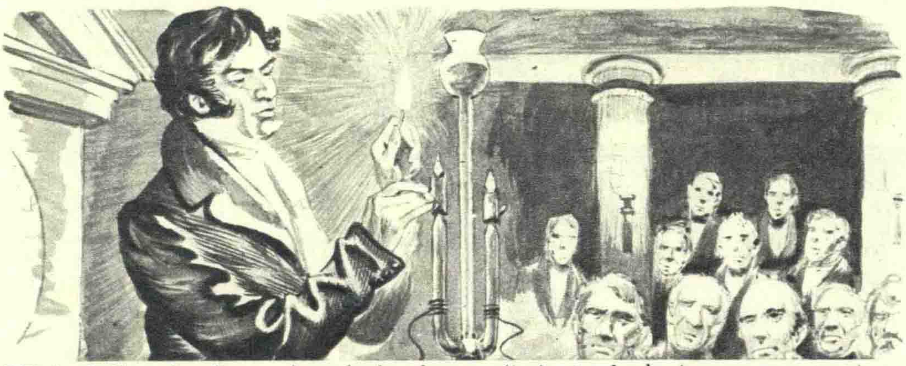
C. T. R. Wilson invented the cloud chamber, an apparatus for tracing the paths of atomic particles. He found that in an atmosphere saturated with water vapour, when the air is suddenly cooled to cause condensation, the tracks of the particles are made visible.



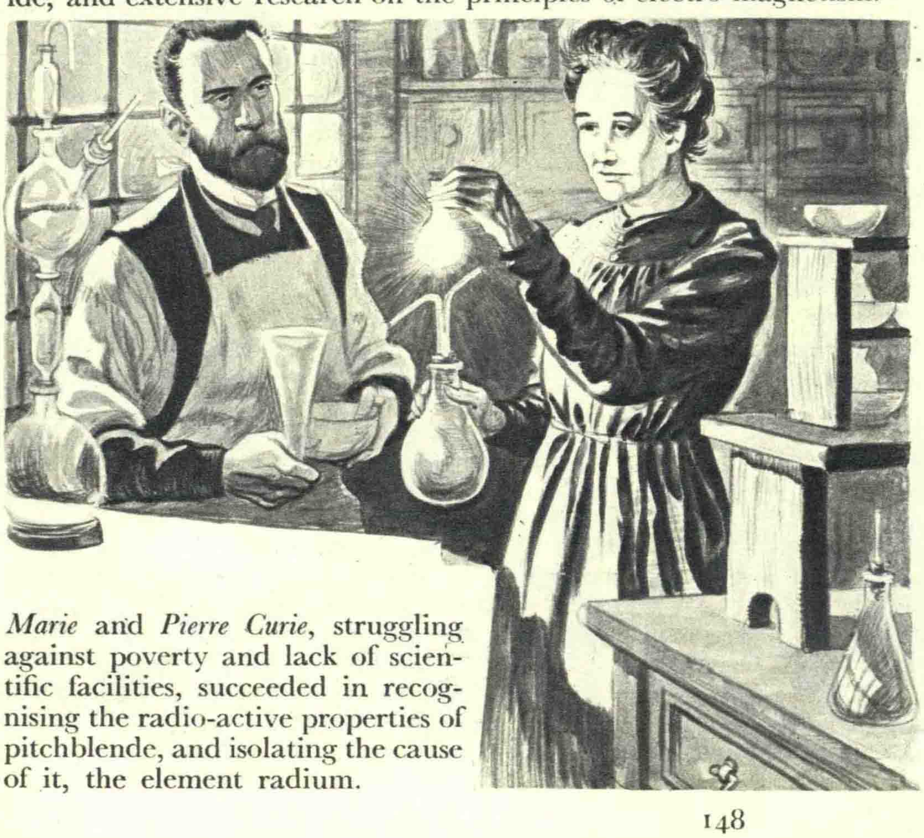
Sir John Cockcroft and *Dr. Walton* bombarded atoms of lithium with a stream of high-speed protons and found that when a collision occurred a lithium atom was broken up.

The Chemists

Chemistry developed more slowly than other sciences in the early stages owing to Aristotle's mistaken ideas of the composition of matter (see page 141). Until Joseph Priestley's discovery, for example, the existence of oxygen was not known. Instead a complicated theory of "phlogiston" (a combustible substance) was in favour. These misconceptions removed, the way was open for an examination of chemical processes and the discovery of the elements. In 1777 Lavoisier demonstrated the nature of air, combustion and the respiration of plants. Dalton's atomic theory revolutionised thinking about chemical reactions. A distinction was made between organic and inorganic chemistry, and in the nineteenth century organic chemists made great strides in preparing the synthetic dyes, drugs and plastics. The discovery of radio-activity, the isolation of radium by the Curies, and the use of X-rays have been other important landmarks.

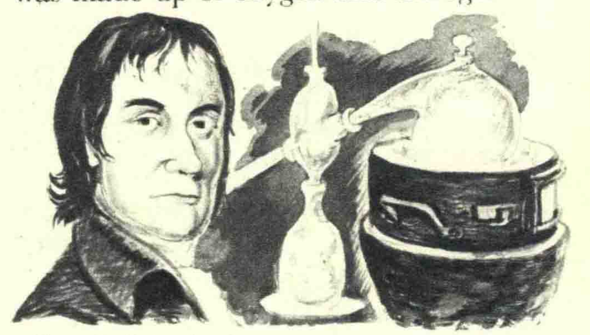


Michael Faraday formulated the laws of electrolysis (see page 202), about which he lectured to the Royal Institution. Faraday's other discoveries included the liquefaction of chlorine and carbon dioxide, and extensive research on the principles of electro-magnetism.

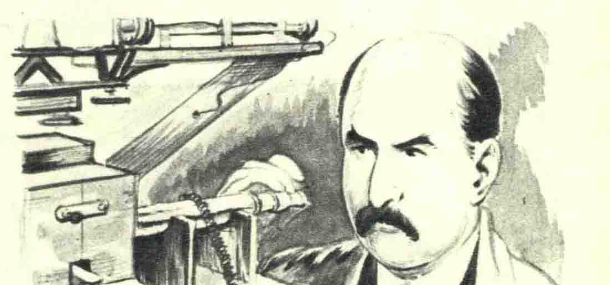


Marie and *Pierre Curie*, struggling against poverty and lack of scientific facilities, succeeded in recognising the radio-active properties of pitchblende, and isolating the cause of it, the element radium.

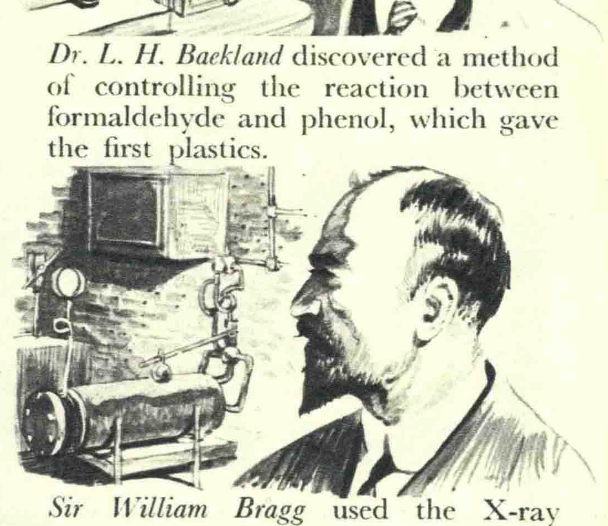
Antoine Lavoisier disposed of *Aristotle's* theory that matter is made up of the four elements, and showed that air was made up of oxygen and nitrogen.



Joseph Priestley invented the pneumatic trough for collecting gases and discovered the existence of oxygen.



Dr. L. H. Baekland discovered a method of controlling the reaction between formaldehyde and phenol, which gave the first plastics.



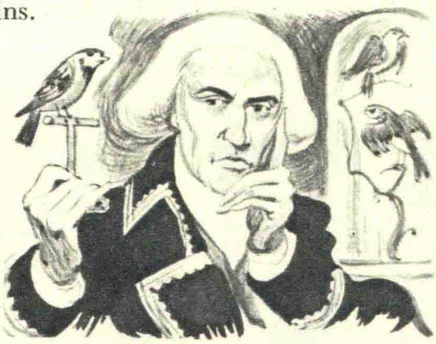
Sir William Bragg used the X-ray spectrograph to examine the structure of crystals.

Plants and Animals

The sciences of biology and medicine were handicapped for thousands of years because of mistaken ideas of the nature of life and the functioning of the organs of the body. It was believed that there were two kinds of blood in the body, which flowed separately through the arteries and the veins. Harvey's discovery in 1628 that the blood circulates from the heart to the arteries and returns via the veins marked a great advance. It was the prelude to a number of important investigations into the working of the respiratory and glandular systems.

The Swedish scientist Carl von Linné (Linnaeus) provided a great impetus to biology when he introduced his latinised classification of plants and animals. Buffon, a Frenchman, helped to reorganise zoology by writing a most comprehensive work on animals. Much of the progress in the biological sciences in the nineteenth and twentieth centuries has been concerned with evolution and the problems of heredity. Lamarck, Darwin, Mendel, Huxley are but a few of the famous names involved in research of this kind.

William Harvey, after studying the way in which the valves in the veins work, came to the conclusion that the blood circulates out from the heart through the arteries and returns through the veins.



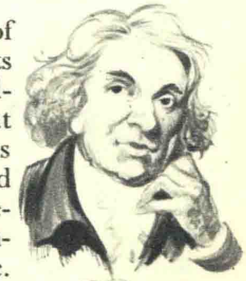
Jean Baptiste Lamarck advanced the idea that evolution of the animals was caused by the inheritance of acquired characters. Constant use of abilities tended to develop them, whilst unnecessary ones were lost.

Jean Fabre conducted many investigations into the behaviour of insects and showed that although many of their activities appear to have a purpose, this does not mean that insects can reason.

Sir Joseph Hooker's observations of the similarities between plants led him to believe that there might have been a land connection between South America and Australia in fairly recent times.

Sir James Simpson pioneered the use of chloroform as an anaesthetic. A surgeon by profession, he helped to found the modern science of gynaecology, and used chloroform for childbirth.

Linnaeus discovered many new species of plants, but is best known for the method he developed of classifying animals and plants by means of a Latin name in two parts (genus and species.)

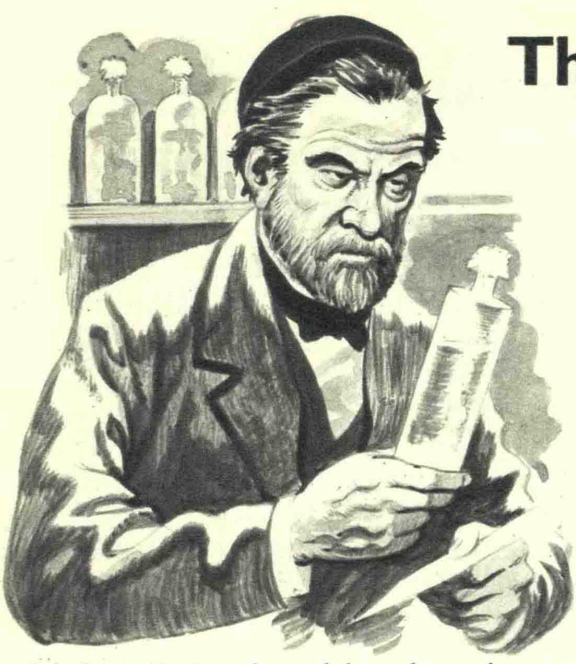


John Hunter was one of the greatest anatomists and a founder of modern surgery. A great experimenter, he is said to have dissected over 500 different species of animals to improve his knowledge.

Ernst Haeckle was a keen supporter of Darwin's theory of evolution. He was the first to attempt to draw a genealogical tree showing the relationships between the various orders of animals.

Ivan Pavlov studied the nervous system in animals and especially reactions to stimuli called reflex actions. He found that he could teach animals new reflexes (conditioned reflexes).

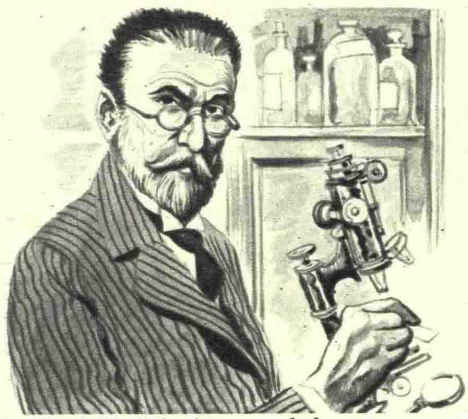
The World of the Microscope



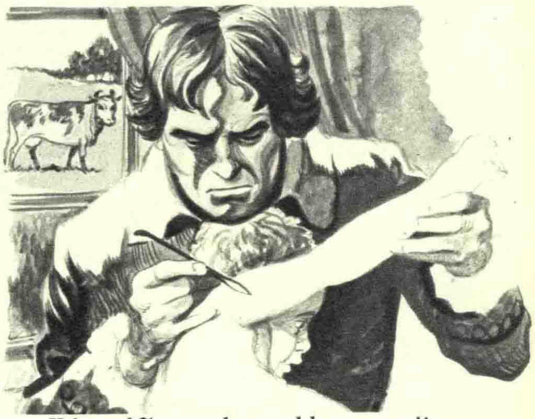
Louis Pasteur showed how bacteria were responsible for decay and disease in foods. His most famous achievement was to find a way to destroy harmful bacteria in milk by heating it (pasteurisation—see page 253).

The microscope, once perfected as an instrument for examining micro-organisms and tissues, was a great help in enabling scientists to discover varied forms of bacteria. Pasteur was able to identify and find methods of rendering harmless the bacteria in milk, and to control those harming the fermentation of wine. The science of bacteriology has developed largely from his work and has made great strides in controlling harmful germs both by chemical and biological means. Jenner's discovery early in the nineteenth century of the method of inoculation against smallpox has had tremendous consequences in the field of preventive medicine. The realisation by Schwann and Schleiden in 1838 that the cell is the basic unit of living tissue has enabled geneticists to give an explanation of the Mendelian principles of heredity, and has led to a better understanding of the structure of living things. Some of the most interesting discoveries in this field in recent years have resulted from the work of Lederburgh, who found that cross-over (see page 51) occurs in bacteria.

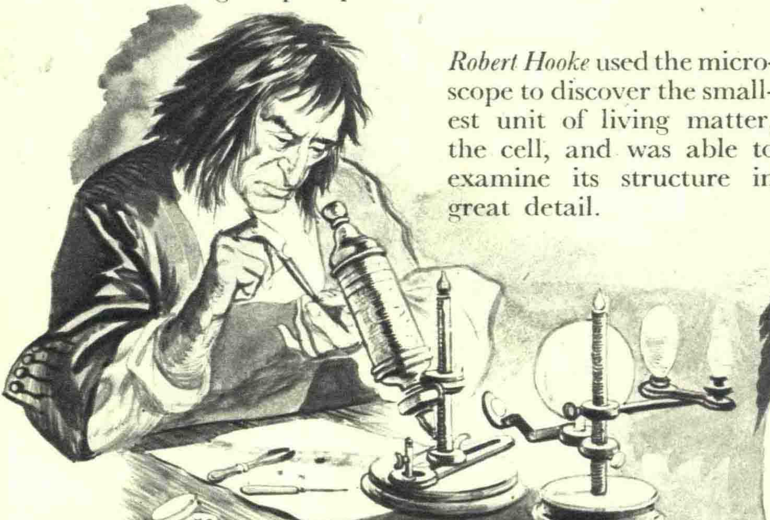
Gregor Mendel provided the basis of the modern science of genetics, after years of studying the interbreeding of pea plants.



Paul Ehrlich pioneered the treatment of infectious diseases by chemical means, using poisonous dyes which were absorbed by microbes.



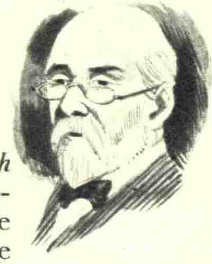
Edward Jenner showed how smallpox could be prevented in human beings by inoculation with vaccine from a cow suffering from cowpox.



Robert Hooke used the microscope to discover the smallest unit of living matter, the cell, and was able to examine its structure in great detail.

(*Right*) *Joseph Lister*, a great surgeon, saw the need for antiseptics, using carbolic acid to kill dangerous bacteria in wounds.

(*Left*) *Sir Alexander Fleming* discovered the mould penicillium, from which the drug penicillin was later prepared.



(*Right*) *Robert Koch* discovered that infectious diseases are carried from one person to another by microbes or germs.

Famous Discoverers

Ampère, André Marie (1775-1836), France, physicist and mathematician. Experimented in electro-magnetism and dynamics. Derived the ampère, unit of strength of the flow of an electrical current.

Appleton, Sir Edward Victor (1892—), Britain, physicist. Investigated transmission of radio waves. Discovered Appleton layer of the ionosphere which reflects waves, bending them round the earth.

Archimedes (287-212 B.C.), Greece, mathematician and physicist. Discovered Archimedes principle (see page 141), the archimedean screw, and certain laws of levers.

Aristotle (384-322 B.C.), Greece, philosopher. Believed in the four elements of nature (see page 141). This erroneous idea had much influence on scientists as late as the Middle Ages.

Arrhenius, Svante August (1859-1927), Sweden, chemist. Established theory of electrolytic dissociation. Considered that in watery solution nearly all the molecules of an electrolyte are changed into equal numbers of positively and negatively charged ions.

Avogrado, Amedeo (1776-1856), Italy, physicist. Discovered Avogrado's law, stating that equal volumes of all gases at standard temperature and pressure contain the same number of molecules.

Bacon, Francis, Lord Verulam (1561-1626), Britain, scientist and philosopher. Wrote about the need for experiment in science, the only way to achieve the truth.

Bacon, Roger (1214-1294), Britain, Franciscan friar and scientist. Made important researches into optics and mechanics. Sometimes considered (wrongly) to be inventor of gunpowder.

Banting, Sir Frederick Grant (1891-1941), Canada, physician. Discoverer of insulin.

Becquerel, Antoine Henri (1852-1908), France, physicist. Discovered radio-activity of uranium.

Berthelot, Marcellin Pierre Eugène (1827-1907), France, chemist. First demonstrated that organic compounds (fats and sugars) could be synthesised by ordinary chemical methods.

Berzelius, Baron Jons Jakob (1779-1848), Sweden, chemist. Composed system of atomic symbols for the elements, and after extensive research into relative weights of atoms and molecules demonstrated formulae showing by letters and numbers the grouping of the atoms of each element present in a compound. (see page 196).

Blackett, Patrick Maynard Stuart (1897—), Britain, physicist. Used cloud chamber to photograph paths of atomic particles and confirmed that a nitrogen atom that had absorbed an alpha particle, released a proton. Calculations showed that the nitrogen had been transmuted into oxygen.

Bohr, Niels Henrik David (1885—), Denmark, physicist. Built up planetary theory associated with his name. Applied quantum theory to the study of atomic processes.

Boyle, Hon. Robert (1627-1691), Britain, chemist and physicist. Found that there were two different kinds of electrical charges, positive and negative. Formulated Boyle's law (the volume of a gas varies inversely with the pressure).

Bragg, Sir William Henry (1862-1942), Britain, physicist and chemist. Used X-rays to analyse the structure of crystals (see Bragg, Sir W. L.).

Bragg, Sir William Lawrence (1890—), Britain, physicist and chemist. With his father, Sir W. H. Bragg, worked on crystal structure, determined law governing the diffraction of X-rays by the planes of a crystal.

Brahe, Tycho (1546-1601), Denmark, astronomer. Built an observatory near Copenhagen, and amassed a set of observations of heavenly bodies more complete than any previously.

Brown, Robert (1773-1858), Britain, botanist. Described *Brownian movements* of living protoplasm (see page 52), and discovered cell nucleus.

Cannizzaro, Stanislao (1826-1910), Italy, chemist. Showed how the atomic weights of elements in volatile compounds can be ascertained from the molecular weights of the compound.

Cavendish, Hon. Henry (1731-1810), Britain, chemist and physicist. Investigated nature of gases. Discovered hydrogen.

Chadwick, Sir James (1891—), Britain, physicist. With Lord Rutherford discovered the neutron in the atom.

Cockcroft, Sir John Douglas (1897—), Britain, physicist. With Dr. E. T. S. Walton carried out pioneer work on transmutation of atoms, using artificially accelerated particles.

Copernicus, Nicolaus (1473-1543) Poland, astronomer. Developed idea that the earth moves round the sun. Met much opposition especially from the Church, whose leaders believed the sun and planets moved round the earth.

Crookes, Sir William (1832-1919), Britain, chemist and physicist. Invented the Crookes' tube, and carried out experiments which revealed the nature of cathode rays.

Curie, Sklodowska Marie (1867-1934) and **Curie, Pierre** (1859-1906), Marie b. Poland, went to France married Pierre, chemists. Isolated radium from pitchblende.

Cuvier, Baron Georges Leopold Chrétien Frederic Dagobert (1769-1832), France, zoologist and geologist. Studied comparative anatomy and palaeontology. Rejected idea of continuous evolution.

Dalton, John (1766-1844), Britain, chemist and mathematician. Proposed the atomic theory of matter from which modern chemistry has developed (see page 195).

Darwin, Charles Robert (1809-1882), Britain, biologist. After investigating plant and animal life in Galapagos Islands became convinced of idea of evolution (see page 251). Wrote *Origin of Species*, explaining this thesis.

Davy, Sir Humphry (1778-1829), Britain, chemist and physicist. Discovered nitrous oxide could be used as an anaesthetic. Discovered sodium, potassium, magnesium, and other alkali metals. Invented the Davy safety lamp for use in mines.

Democritus (*c* 460-370 B.C.), Greece, physicist and philosopher. First stated law of conservation of matter an atomic theory. of conservation of matter and atomic theory.

Dewar, Sir James (1842-1923), Britain, chemist and physicist. Invented Dewar vacuum flask. Experimented on properties of matter at low temperatures. Liquefied and solidified hydrogen.

Eddington, Sir Arthur Stanley (1882-1944), Britain, astronomer. Made notable contributions to astrophysics, especially concerned with the evolution of stars.

Ehrlich, Paul (1854-1915), Germany, bacteriologist. Did important work on cancer and diphtheria. Developed methods of treating infectious diseases by chemical means.

Einstein, Albert (1879-1955), *b.* Germany, went to U.S.A., mathematician and physicist. Wrote *General Theory of Relativity*, revising fundamental ideas of gravitation, relating mass to energy, and showing that space and time were inseparable concepts.

Fabre, Jean Henri (1823-1915), France, naturalist. Wrote books based on his close observations of insect life.

Faraday, Michael (1791-1867), Britain, chemist and physicist. Discovered principle of electro-magnetic induction used in the dynamo. Also liquefied chlorine and formulated laws of electrolysis.

Fleming, Sir Alexander (1881-1955), Britain, bacteriologist. Discovered the mould culture penicillium from which the healing drug penicillin was developed.

Franklin, Benjamin (1706-1790), U.S.A., statesman and physicist. Proved by experiment that lightning is a form of electricity.

Galen, Claudius (130-200), *b.* Greece, went to Italy, physician. Wrote many books helping to reduce the chaotic state of learning in medicine at the time.

Galileo Galilei (1564-1642), Italy, mathematician and astronomer. Made the first astronomical telescope, and proved that the sun is the centre of the solar system. Investigated behaviour of falling bodies.

Galvani, Luigi (1737-1798), Italy, physicist and physiologist. Discovered what he called Galvanism, animal electricity, as a result of his experiment with the frogs' legs (see page 202).

Gay-Lussac, Joseph Louis (1778-1850), France, chemist. Demonstrated proof of Dalton's atomic theory (see Dalton, J.), and made balloon ascents to study atmospheric conditions and magnetism.

Gilbert, William (1543-1603), Britain, physician and physicist. Demonstrated poles of magnet, and discovered that the earth is itself a magnet. Did research into static electricity.

Guericke, Otto von (1602-1686), Germany, physicist. First succeeded in creating a vacuum artificially. Also made friction machine for generating electricity.

Haeckel, Ernst Heinrich (1834-1919), Germany, biologist. Did important work on theory of evolution by research with sponges, jellyfish and corals.

Harvey, William (1578-1657), Britain, physiologist. Discovered circulation of the blood.

Hero of Alexandria (*c.* 100?), Egypt, mathematician and inventor. Studied mechanics, geometry, and pneumatics. Invented many devices worked by steam, compressed air, and water.

Herschel, Sir William (1738-1822), *b.* Germany, went to Britain, astronomer. Suggested use of spectral lines for identifying elements. Discovered Uranus.

Hertz, Heinrich (1857-1894), Germany, physicist. Discovered radio waves and demonstrated the similarity between the behaviour of light, heat, and electromagnetic waves.

Hooke, Robert (1635-1703), Britain, biologist and physicist. Discovered that living matter is made up of cells. Worked with Boyle on combustion and respiration and individually on many problems in physics.

Hooker, Sir Joseph Dalton (1817-1911), Britain, botanist. Founder of the science of plant ecology, especially in Australia and New Zealand. Realised the importance of diatoms in nature (see page 49).

Humbolt, Baron Alexander von (1769-1859), Germany, geographer, Made first map showing isothermal lines. Showed linear character of volcanic groupings.

Huxley, Thomas Henry (1825-1895), Britain, biologist. Upholder of Darwin's theory of evolution. Conducted a wide range of research in zoology, especially concerning marine creatures.

Huygens, Christiaan (1629-1695), Netherlands, astronomer. Discovered Saturn's fourth moon and rings, and proposed the wave theory of light.

Jenner, Edward (1749-1823), Britain, physician. Discovered method of preventing smallpox by vaccination (see page 253).

Joliot-Curie, Jean Frédéric (1900—), France, physicist. With his wife discovered artificial radio-activity. Also investigated the energy of electrons.

Kelvin, Lord William Thompson (1824-1907), Britain, mathematician and physicist. Made many investigations into the measurement of heat, especially the cooling of gases on expansion, and the flow of heat from one object to another. Concluded that an energy source cooler than its surroundings could not transmit heat to them. He carried out research over a vast range of science.

Kepler, Johann (1571-1630), Germany, astronomer. Formulated planetary laws, known as Kepler's laws.

Koch, Robert (1843-1910), Germany, bacteriologist. Investigated bacillus of tuberculosis, and studied life cycle of bacteria causing anthrax in cattle.

Lamarck, Jean Baptiste (1744-1829), France, naturalist. Put forward theory of evolution by the inheritance of acquired characters.

Lavoisier, Antoine Laurent (1743-1794), France, chemist. Discovered composition of air, and showed that all chemical reactions could be represented by equations. The phlogiston theory was finally overthrown by his work on combustion.

Leeuwenhoek, Antony van (1632-1723), Netherlands, biologist. Used microscope in wide range of observations covering weevils, fleas, aphids, and blood corpuscles.

Liebig, Justus von (1803-1873), *b.* Germany, went to France, chemist. Improved technique of organic analysis, discovered chloroform.

Linnaeus, Carolus (1707-1778), Sweden, botanist. Developed system of classification of plants, still used in a modified form today.

Lister, Lord Joseph (1827-1912), Britain, surgeon. Realised the danger of infection of wounds during operations and used carbolic acid as an antiseptic.

Lovell, Alfred Charles Bernard (1913—), Britain, mathematician and astronomer. Leads scientific team at the Jodrell Bank radio telescope (see page 136), whose best known achievements have been in tracking space rockets, and in the study of electrical disturbances in space.

Lyell, Sir Charles, (1797-1875) Britain, geologist. Established idea that rocks on the earth are still being laid down. The crust is still being changed by water, glaciation, earthquakes etc., as in ancient geological times.

Maskelyne, Nevil (1732-1811), Britain, astronomer. Evolved method of finding longitude at sea by lunar distances. Weighed the earth using the effects of gravitational force (see page 144).

Maxwell, James Clerk (1831-1879), Britain, physicist. Studied heat properties of gases. Predicted existence of radio waves before they were discovered, and completely changed electrical theory with his electromagnetic theory of light.

Mendel, Gregor Johann (1822-1884), Austria, priest and geneticist. Established by thorough experiment the laws which govern heredity, mainly by studying the growth of peas under controlled conditions.

Mendeléef, Dmitri Ivanovich (1834-1907), Russia, chemist. Famous for work on the Periodic Law, in which he showed that if elements were arranged in order of atomic weights they fall into related groups.

Newton, Sir Isaac (1642-1727), Britain, mathematician. Invented calculus and first stated the law of gravitational forces. Made important discoveries in optics.

Oersted, Hans Christian (1777-1851), Denmark, physicist. Did important work on the magnetic properties of electrical currents.

Ohm, Georg Simon (1787-1854), Germany, physicist. Put forward Ohm's law, stating that the strength of an electrical current through a circuit is equal to the electro-motive force divided by the resistance of the wire.

Pasteur, Louis (1822-1895), France, bacteriologist. Invented technique of pasteurisation to kill bacteria in foods (see page 253). Established treatment for anthrax, hydrophobia and other diseases by inoculation.

Pavlov, Ivan Petrovich (1849-1936), Russia, physiologist. Studied conditioned reflexes in the nervous system, especially in animals.

Perkin, Sir William Henry (senior) (1838-1907), Britain, chemist. Discovered Mauveine, the first dye made synthetically from coal tar chemicals and the forerunner of the modern colour industry.

Perkin, William Henry (junior) (1860-1929), Britain, chemist. Made outstanding contributions to organic chemistry, many of which had industrial importance.

Planck, Max (1858-1947), Germany, physicist. Produced Quantum theory, a concept of energy consisting of minute packages called quanta, the energy of which varies with the frequency of emission.

Priestley, Joseph (1733-1804), Britain, chemist. Invented pneumatic trough for collection of gases under water, and discovered the existence of oxygen.

Pythagoras (*c.* 582-500 B.C.), Greece, mathematician and philosopher. Interested in geometry and astronomy. Anticipated many later discoveries.

Ray, John (1627-1705), Britain, naturalist. Made early classification of animals and plants. Originated terms *dicotyledon* and *monocotyledon* (see page 51).

Röntgen, Wilhelm Konrad (1845-1923), Germany, physicist. Discovered X-rays (see page 110).

Rumford, Count (Benjamin Thompson) (1753-1814), U.S.A., physicist. By experiments in boring gun barrels established that heat is produced by friction.

Rutherford, Lord Ernest (1871-1937), *b.* New Zealand, went to Britain. Examined process of radio-activity, propounding the nuclear theory of an atom. Split the atom using alpha-rays.

Scheele, Karl Wilhelm (1742-1786), Sweden, chemist. Discovered chlorine, manganese, and many other substances. Discovered oxygen independently from Priestley.

Schleiden, Matthias Jacob (1804-1881), Germany, botanist. Established theory of cell division in growth of plants (see page 51), working with Theodor Schwann.

Simpson, Sir James Young (1811-1870), Britain, surgeon. Pioneered use of anaesthetics in surgery.

Smith, William (1769-1839), Britain, geologist. Found that various rock layers contained fossils of different kinds, and that fossils could be used to identify a rock stratum.

Soddy, Sir Frederick (1877—), Britain, chemist. Established basis of isotope theory.

Stokes, Sir George Gabriel (1819-1903), Britain, physicist. Carried out valuable research into theory of viscous fluids and theory of diffraction in light. Investigated fluorescence.

Thales of Miletus (*c.* 640-546 B.C.), Greece, astronomer and geometer. Early seeker for a theory of matter.

Thomson, Sir Joseph John (1856-1940), Britain, physicist and mathematician. Conducted research in conduction of electricity through gases. Discovered the charge and mass of the electron.

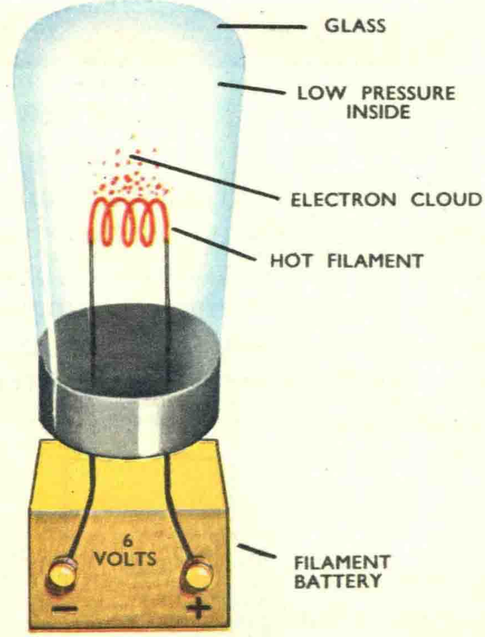
Van't Hoff, Jacobus Hendricus (1852-1911), Netherlands, chemist and physicist. He applied thermodynamics to chemistry, and he also proved that the osmotic pressure of a solution of a given concentration is proportional to the absolute temperature.

Volta, Alessandro (1745-1827), Italy, physicist. Developed the idea of current electricity and invented voltaic pile battery (see page 202).

Wilson, Charles Thomas Rees (1869—), Britain, physicist. Invented cloud chamber, an apparatus for tracking the path of an ionised particle, an important advance in the investigation of atoms.

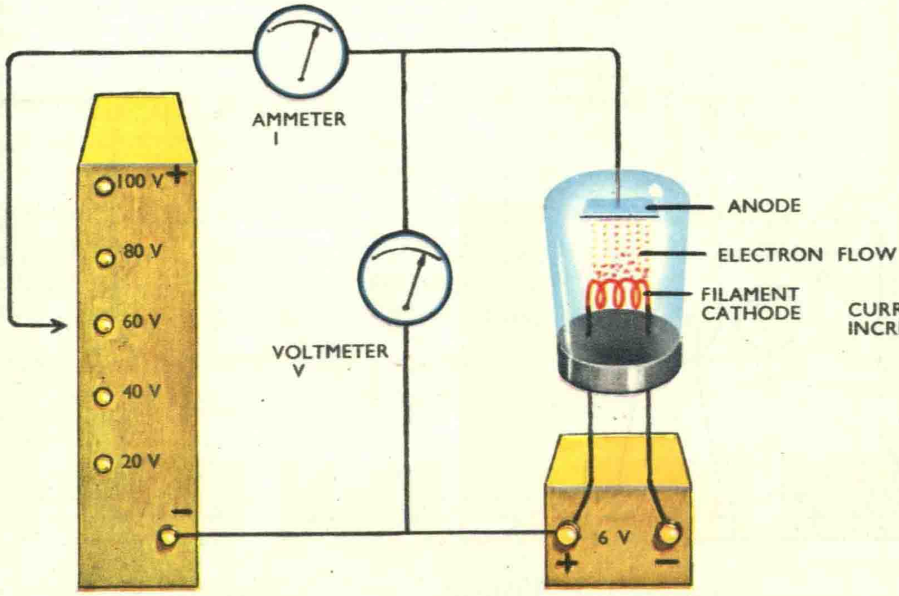
ELECTRONIC SCIENCE

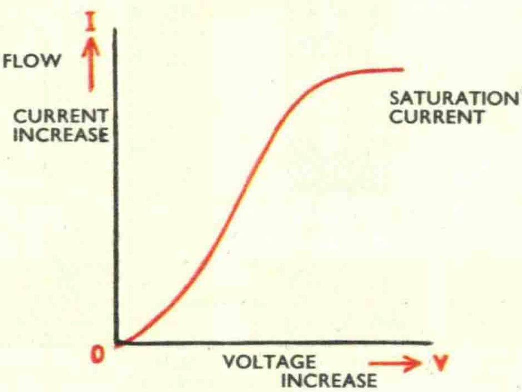
Electronics is the practical use of the way electrons behave. Soon after the discovery of the electron around 1900, experimenters were at work turning this discovery into electronic apparatus. Indeed it is a remarkable achievement that in only sixty years we have such complicated devices as Television, Radar, Computers and Guided missiles. Some of the underlying principles which made these achievements possible are used in the most important single electronic device:—



THE THERMIONIC VALVE

It is best thought of as a pressure driven device which allows flow in one direction only, in other words, what it is popularly called in Britain—a Valve. When a metal is heated in a vacuum to a sufficiently high temperature, some of the electrons just below the surface acquire enough energy to escape, and these form a cloud of electrons (a "space charge") near the surface of the metal. This is termed Thermionic emission. Some metals (*e.g.*, tungsten) and some oxide-coated metals (*e.g.*, thoriated tungsten) have very strong emission, so they are used in thermionic valves.





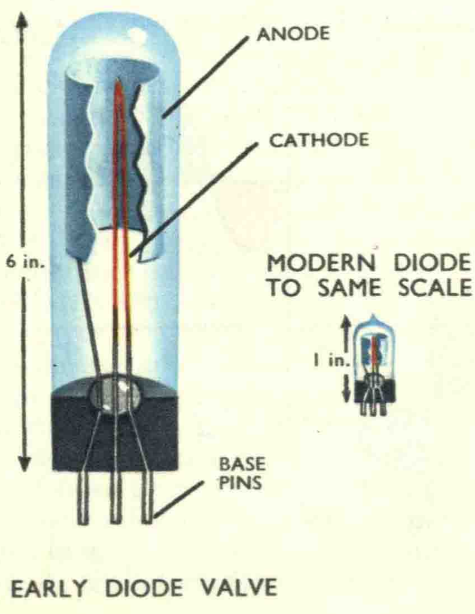
The Diode is the simplest form of Thermionic Valve. It consists of two electrodes —a metal plate called the anode and a metallic strip called the cathode. The cathode can be heated to "red heat" by a filament. The assembly is mounted in an evacuated glass envelope, and connections are made to the electrodes by pins which pass through the glass wall to connection pins.

On heating the filament an electron space charge of negatively charged electrons is formed near the cathode (see electricity). If a positive voltage from a battery is applied to the anode relative to cathode then electrons of the space charge will be attracted towards the positive anode and will cross the empty space between cathode and anode. This electron movement means that a current is flowing in the circuit although there is in fact no normal conductor of electricity (wire) between cathode and anode. Normally this would be a break in the circuit that would prevent current flow.

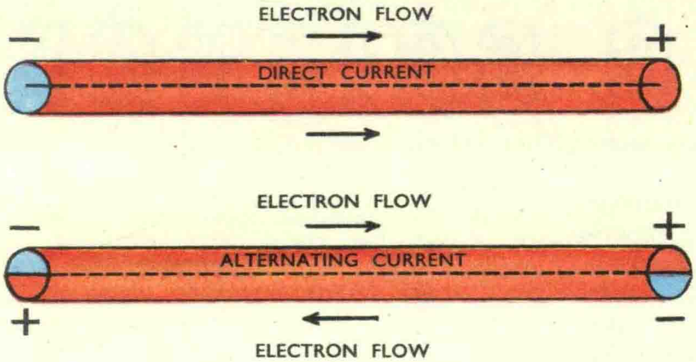
If a negative voltage is applied to the anode, no electron movement can take place (a negative voltage repels the negative electrons of the space charge). Therefore the diode valve can only conduct in one direction from cathode to anode.

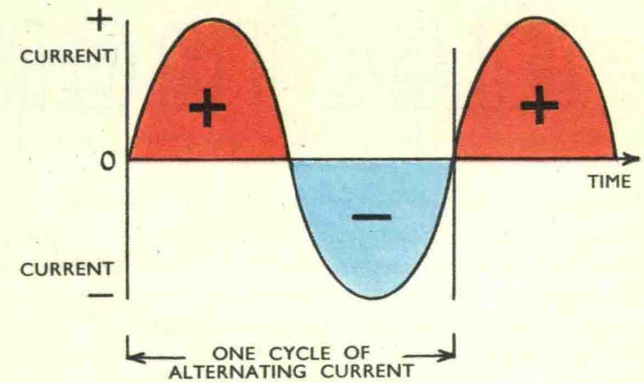
If a voltmeter and ammeter are placed in the circuit as shown and the voltage (V) varied then a graph of current (I) against voltage (V) can be drawn as shown. As the voltage increases so the current increases until for large voltages a saturation current is reached—there is a limit to the current which can be drawn through the valve.

So a diode's limitation of conducting only in one direction (acting as a valve to an electron current) is the reason why it is so greatly used in electronics.



EARLY DIODE VALVE

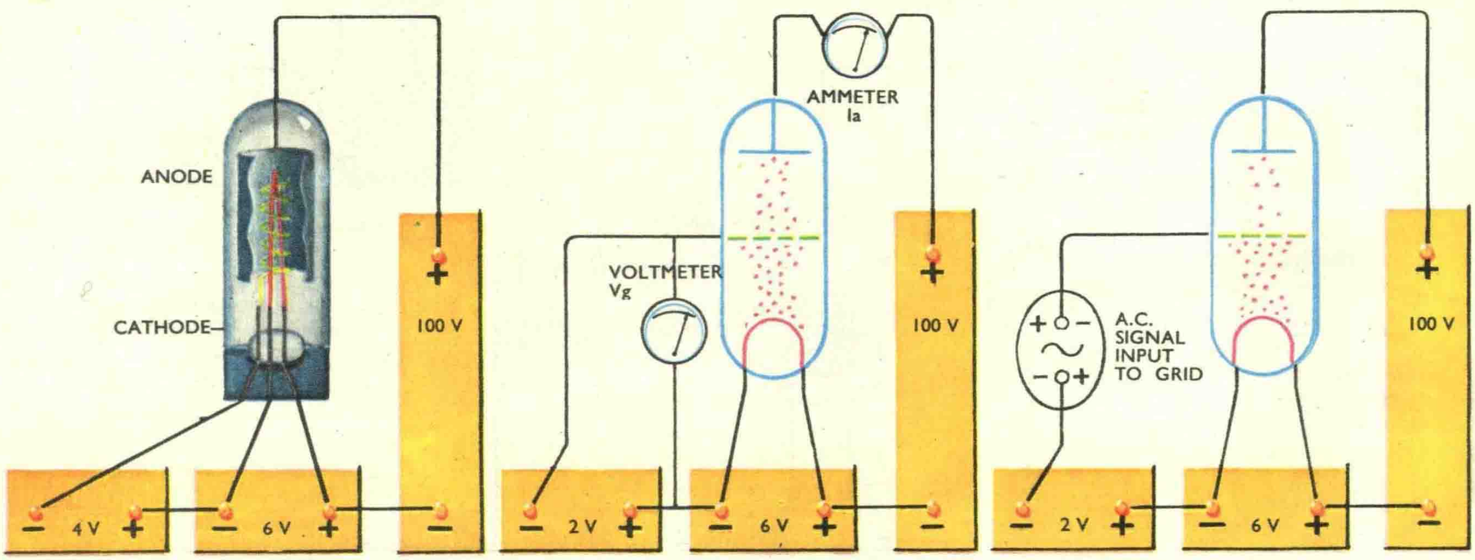




Negatively charged electrons always move towards the positive voltage region in a conductor. If the voltage is maintained at a steady level, then the electron current flow will be continuous and constant in the one direction, and is termed Direct Current (D.C.). If the voltage varies in a rhythmic way, first positive and then negative, then the size and direction of current flow will vary in sympathy. This is termed Alternating Current (A.C.). The A.C. supply in our homes varies rhythmically at fifty cycles every second.

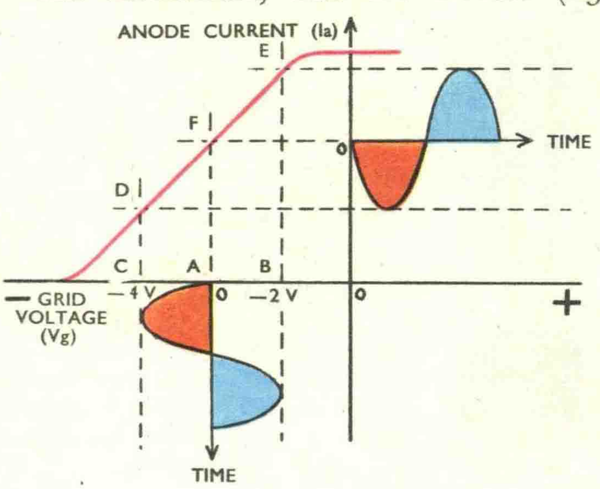
TRIODE VALVE

SIMPLIFIED DIAGRAMS OF TRIODE VALVE



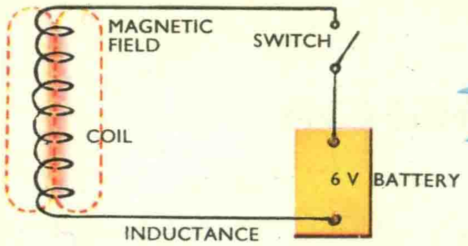
The Triode Valve, reproduces a signal at a much stronger level.

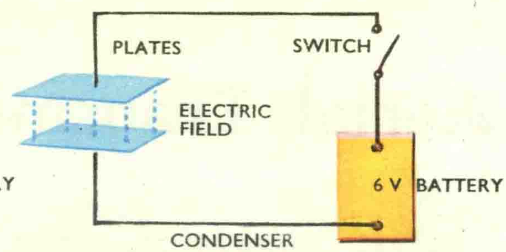
An American, Lee De Forest (1907) invented the Triode Valve. This differs from the Diode in that it has a third electrode named the control grid, formed by a fine spiral of wire wound around and very close to the Cathode. For a given control grid voltage a certain anode current will pass through the grid to the anode. This control grid voltage is usually slightly negative relative to the cathode to prevent the grid from behaving like an anode and collecting electrons.

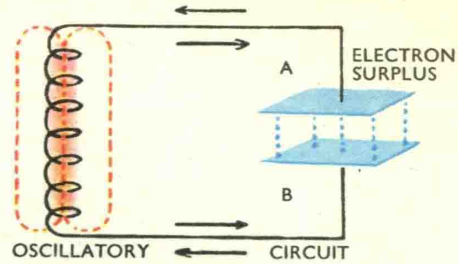


From the graph of grid voltage against anode current, you can see that for a grid voltage of − 2 volts the anode current is BE, and if the grid voltage is made more negative to − 4 volts, then the anode current is reduced to CD. It follows that if the grid voltage is made to vary between − 2 volts and − 4 volts, then the anode current will vary in sympathy between BE and CD.

In this way a varying anode voltage can be obtained that is many times greater than the varying grid voltage. The Triode Valve thus *amplifies* small varying voltages or " signals " applied to its control grid.







INDUCTANCE. This is formed by a coil of wire. When a steady current flows in a coil a magnetic field is produced around it. If a battery is connected across a coil, at first there will be no current flow, the voltage must first begin to build its magnetic field. The field will build up to a steady value and at the same time the current will steadily build up. The voltage across the coil at any instant is directly related to the *rate* at which the current grows.

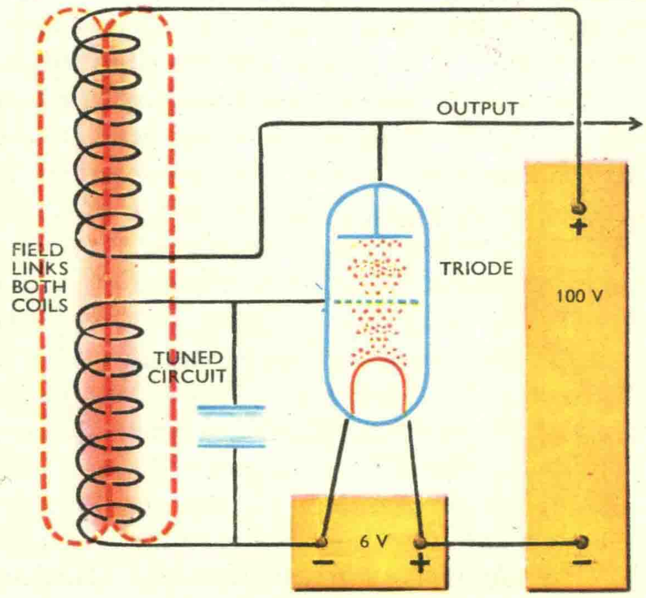
CONDENSER. This is formed by two metal plates spaced apart from one another. When a steady voltage exists across the plates an electric field is produced in the space between them. If a battery supplies a current or charge to the plates, at first no voltage will occur across the plates, the current must first begin to build the electric field. The field will build up to a steady value and at the same time the voltage will steadily build up. The flow of charge on to the condenser plates at any instant is directly related to the *rate* at which the voltage across the plates grows.

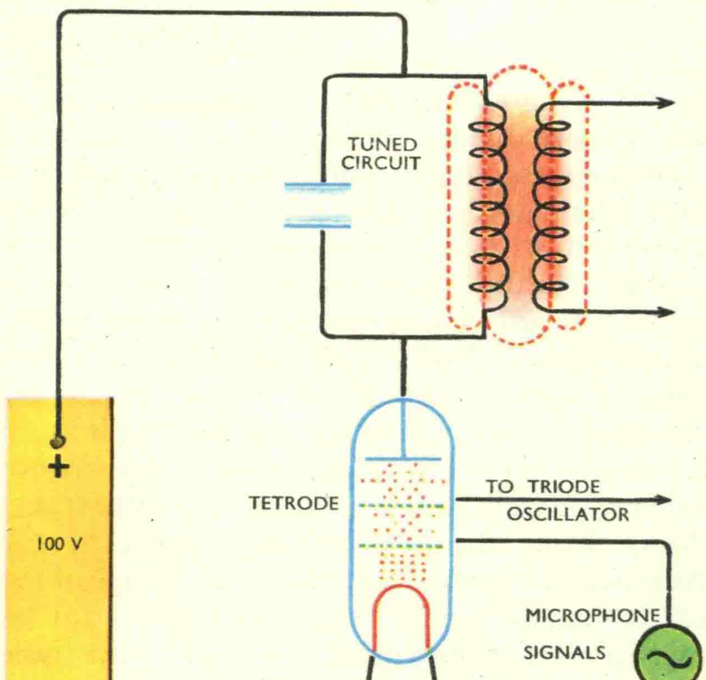
OSCILLATORY CIRCUIT. Suppose at first we have a voltage across the condenser plates, this means that we have a surplus of electrons on plate A. These will start to flow through the coil, steadily increasing until the magnetic field has been established and the electrons are evenly distributed on both plates. The voltage across the condenser is then zero and the magnetic field starts to collapse because there is no voltage (" pressure ") to maintain it. The field tries in vain to maintain the electron flow which falls with the field to zero, by which time all the electrons are then on plate B. The surplus electrons on plate B now start to flow in the reverse direction and the same thing happens again until they are assembled once more on plate A. Then the whole process repeats itself and would indeed do so indefinitely but for the fact that some of the energy is lost each time the electrons flow, (in the form of heat mainly from the coil which has a certain resistance to electron flow). This oscillation, or surge of electrons backwards and forwards at a frequency determined by the time factor of field building of inductance and capacitance, gradually dies away.

When a guitar string is plucked a sound is heard. This sound is caused by the vibration of the string in the air. The number of times it vibrates in one second is the frequency of the sound. This frequency depends on the length of string and its tautness. For each sound there is a particular frequency.

In electronics the range of frequency is extended far beyond what the ear can hear, up to ten thousand million vibrations every second.

A condenser and an inductance are used to produce electrical vibrations. Their actual size determines the frequency of the vibration they produce.

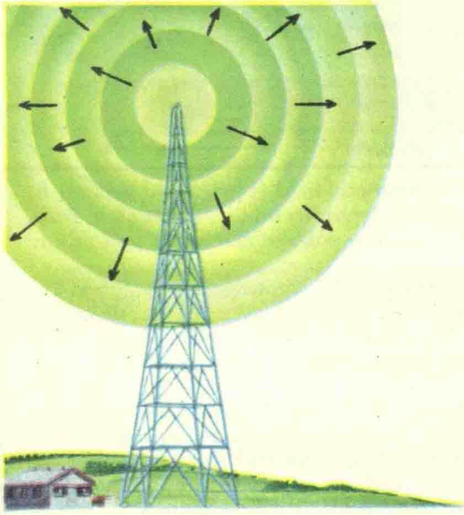


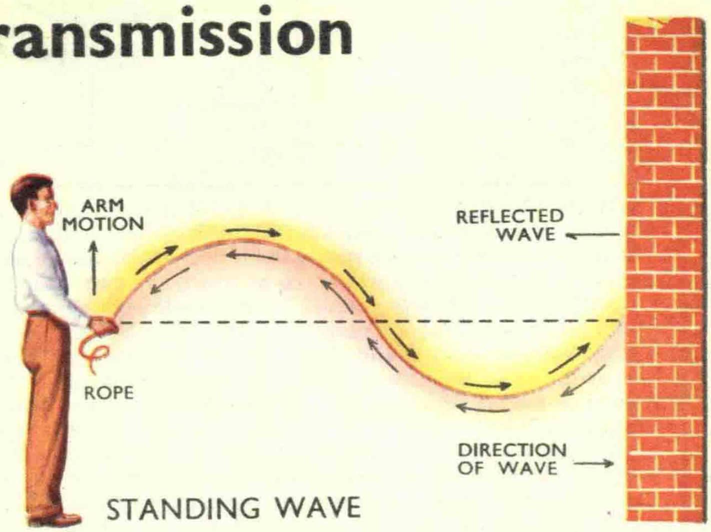


TRIODE OSCILLATOR. This circuit is so designed that it can prevent the oscillations from dying away. It has two oscillatory circuits both working at the same frequency but positioned so that their magnetic fields link one another. The voltage oscillations from one circuit are connected to the grid of a Triode where they are amplified and appear in a similar circuit connected to the anode. The oscillations in the anode circuit link through the magnetic field with the grid circuit where they induce a voltage in sympathy of sufficient strength to maintain the oscillations. The net result is that we have an oscillating voltage at the anode many times greater but in sympathy with the varying (oscillating) voltage at the grid.

TETRODE MIXER. The tetrode has two control grids so that the signals of different frequency can be applied to the electron stream at the same time. This results in the bigger signal of the high frequency having a variation in strength at the frequency of the smaller signal. Usually the bigger signal is produced by an oscillator and the smaller signal from a microphone. A circuit in the anode responds to the oscillator frequency. This forms the basis of the mixing of low voice frequency and transmittably high radio frequency ready for a radio broadcasting transmission.

Aerial Transmission

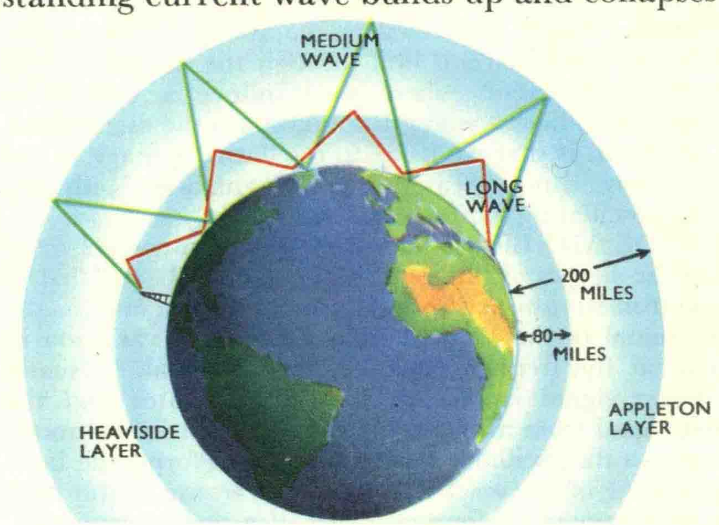




When waves are made to travel along a rope, reflections from the fixed end are seen to travel back along it. By adjusting the rhythm and length of rope, it is possible to synchronise the waves being sent along the rope with those returning. The whole system then appears to be stationary with just the amplitude rising and falling. This is what happens in a transmitting aerial.

The electrical current wave for transmission travels along the aerial, is reflected from the far end, and travels back. If the length of the aerial is just half of one wave, then half of one stationary wave is formed on the aerial. This standing current wave builds up and collapses and as it does so it causes a magnetic field to build up and collapse. As this field collapses much of its energy is radiated as an electromagnetic wave at the frequency of the collapsing field. This radio wave travels at the speed of light (186,000 miles per second) through space.

If it should pass a receiving aerial tuned to this frequency that is of the same length as the transmitting aerial, then the magnetic field of the wave will induce a current in the aerial (but of course much smaller than that radiated from the aerial). This small signal can be amplified in the receiver and detected.

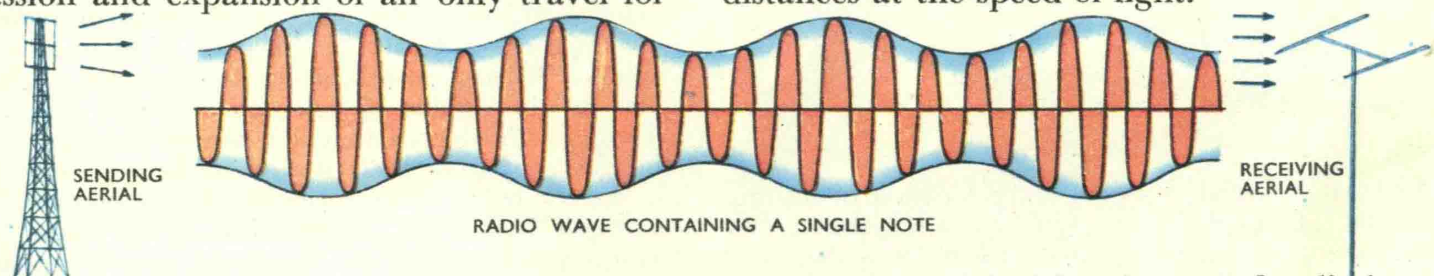


When a radio wave is radiated from a transmitting aerial it behaves in many respects like a light wave. Just as light waves are reflected from polished surfaces so radio waves are reflected from the earth's surface and certain layers of charged particles in the earth's atmosphere. A radio wave which is unable to travel direct from the transmitting aerial to the receiving aerial because of the curvature of the earth can, however, reach such an aerial by multiple reflections from the earth and these layers.

This means that it is possible to communicate by radio over the whole of the earth's surface.

Transmission and Detection

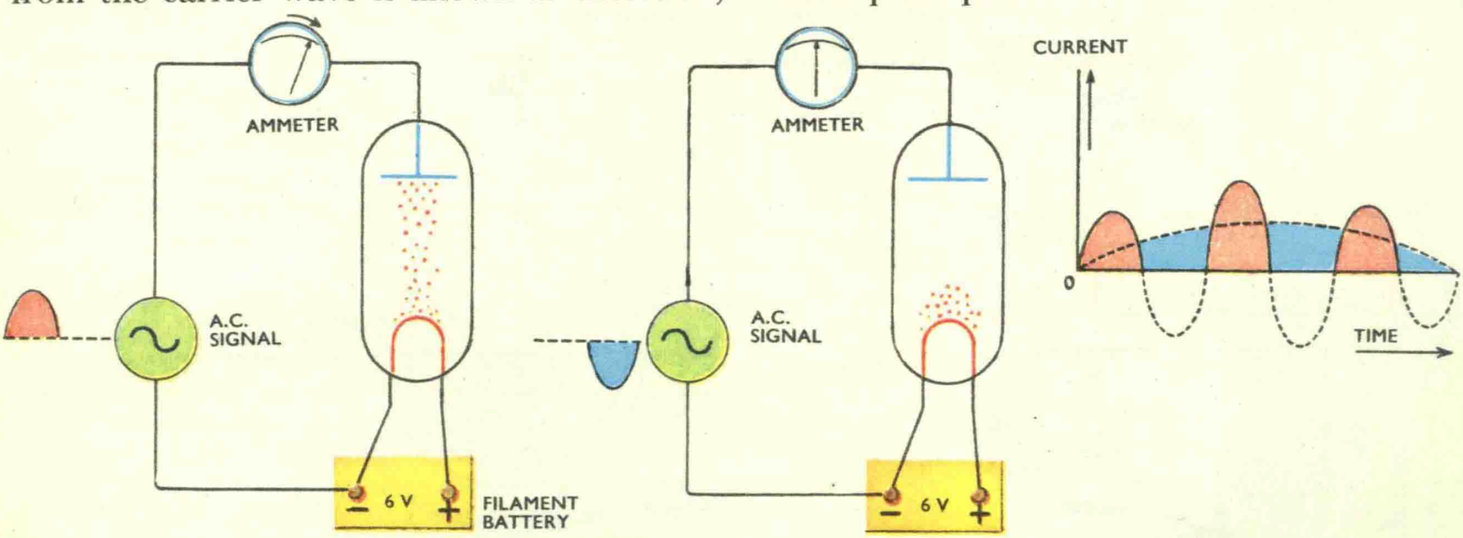
In communications we wish to send speech or sound over long distances. Unfortunately sound waves which are formed by the compression and expansion of air only travel for very short distances before they die away. There is a type of wave called an electromagnetic wave which will travel over long distances at the speed of light.

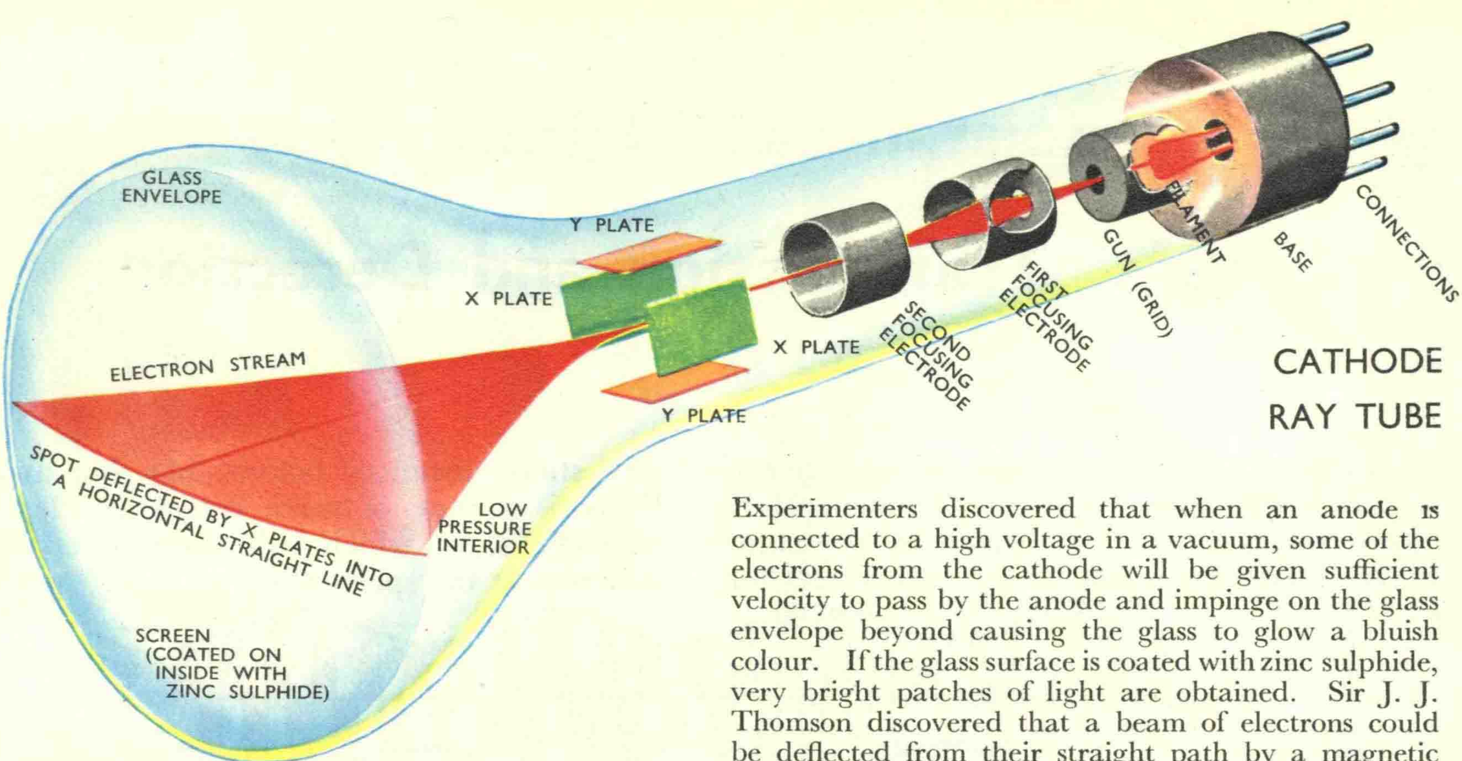


In a radio broadcasting system the sound waves in the studio are picked up by a microphone which converts them into tiny electrical voltages. These small voltages are imposed as a variation of strength (termed Amplitude Modulation) on a constant frequency wave (termed Carrier). This amplitude modulated carrier is radiated as an electromagnetic wave from a transmitting aerial. The frequency of the carrier is the number of complete waves or cycles which pass a given point in one second.

A receiving aerial adjusted to receive this wave will convert it into a small voltage which is then amplified by thermionic valves. The process of obtaining the original sound wave from the carrier wave is known as detection, and is accomplished by the use of a diode as follows :—

The radio wave is applied between anode and cathode of the diode. The diode conducts only during the positive peaks of the carrier wave (*i.e.*, when the anode is positive). The group of varying positive peaks is developed across a circuit which can respond only to the outline of the tops of the peaks—it is not fast enough to respond to individual peaks. This varying voltage which is identical to the original voltage from the microphone in the studio is then amplified and used to drive a loudspeaker, which faithfully reproduces the sound waves originating in the studio. It is possible to transmit pictures by using the same basic principles.





CATHODE RAY TUBE

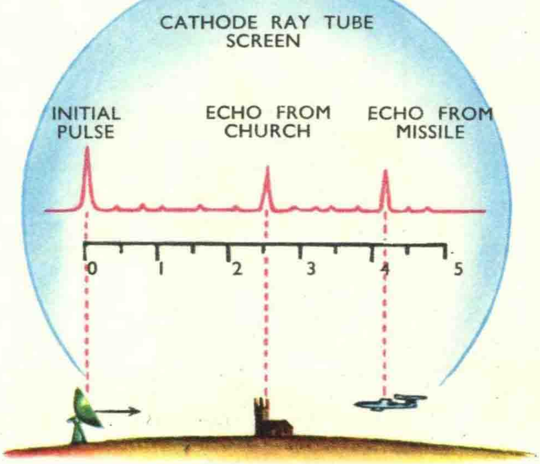
Experimenters discovered that when an anode is connected to a high voltage in a vacuum, some of the electrons from the cathode will be given sufficient velocity to pass by the anode and impinge on the glass envelope beyond causing the glass to glow a bluish colour. If the glass surface is coated with zinc sulphide, very bright patches of light are obtained. Sir J. J. Thomson discovered that a beam of electrons could be deflected from their straight path by a magnetic or electric field. These principles are embodied in the Cathode Ray Tube. Apart from its use in our television sets it plays an important role in scientific research.

In a Cathode Ray Tube electrons from a hot filament (cathode) are accelerated by a high voltage, they pass through the control grid then through narrow cylinders (hollow anodes) which sharply focus the beam. The beam then passes between two sets of plates. The X plates can, when suitable voltages are applied, deflect the beam in a horizontal direction. The Y plates can deflect the beam vertically. The beam then strikes the flat glass surface coated with zinc sulphide giving a sharp spot of light. The brightness of the spot is controlled by the voltage on the control grid.

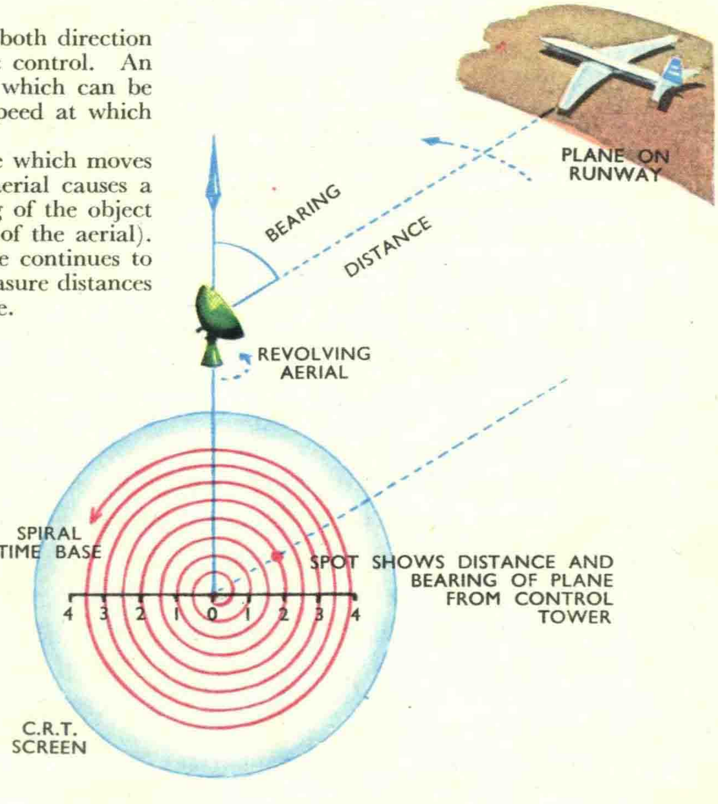
RADAR. Radar is used for the location of moving objects obscured from vision by fog, distance or darkness. In early radar a burst of pulses was radiated from an aerial in a known direction, at the same time the bright spot on the Cathode Ray Tube was made (by the X plates) to cross the tube face horizontally at a constant speed. If an echo is received from an object in the path of the pulses, this can be applied as a voltage to the Y plates pulling the beam out of its horizontal course and causing a "blip" in the trace on the tube face. The tube face can be marked off in miles (the speed of pulses and echoes is always the speed of light—186,000 miles per second) and the operator can read directly the distance away of the object. Its bearing is given by the direction of the aerial.

The plan position indicator P.P.I. gives a complete picture showing both direction and distance. The system is installed at London Airport for traffic control. An aerial rotates slowly at an even speed, sending out bursts of pulses which can be received as echoes before the aerial has moved far because of the speed at which the pulses travel. (186,000 miles per second.)

The aerial rotates in time with the electron beam on the C.R.T. face which moves in a spiral from the centre outwards. Any echo received by the aerial causes a brightening of the spiral trace which shows the distance and bearing of the object from the centre of the tube face (which corresponds to the position of the aerial). C.R.T.s used for Radar usually have long after-glows, (*i.e.*, the tube continues to glow after the spot has moved on). This enables the operators to measure distances and bearings with ease.

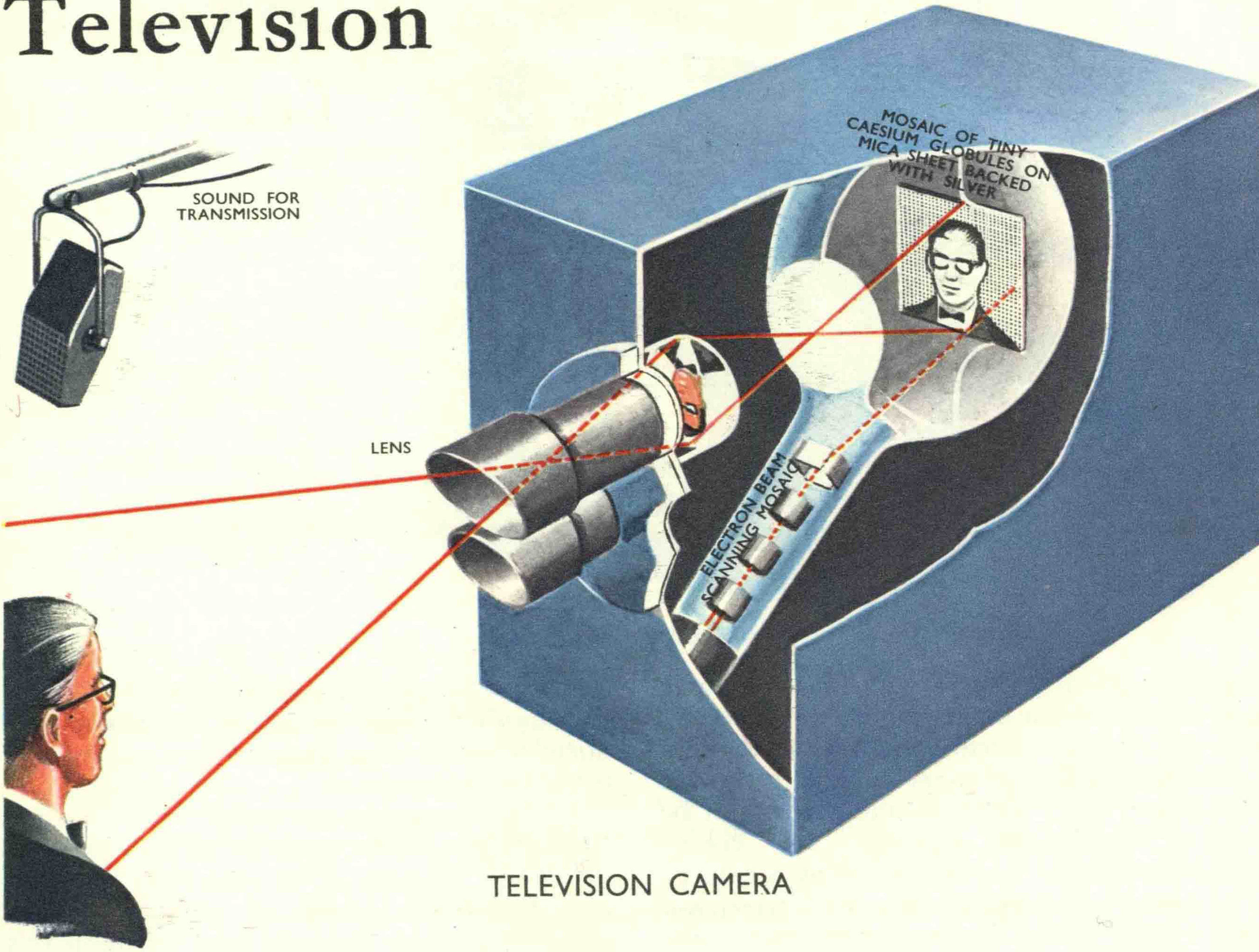


EARLY RADAR



PLAN POSITION INDICATOR (PPI)

Television



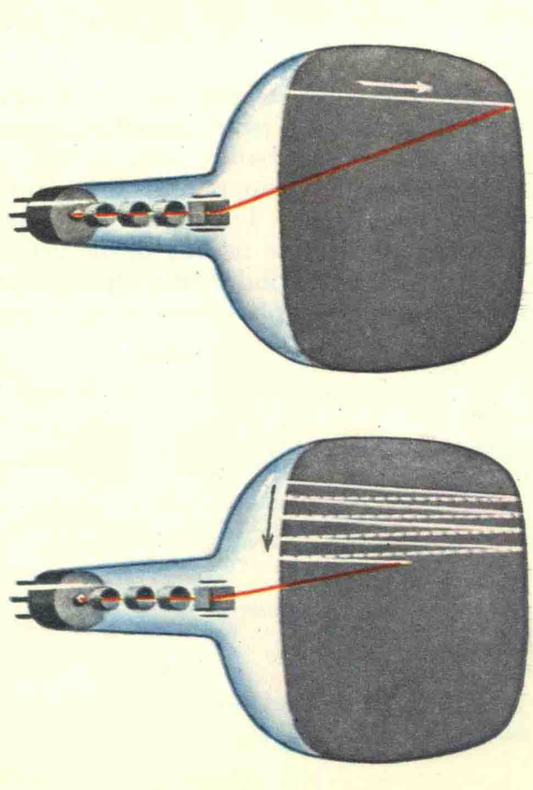
TELEVISION CAMERA

As you read the words on this line your eyes cross from left to right, quickly return to the beginning of the next line and move across again. As this process is carried out the brain receives and stores the information that the eyes see. A television camera works on the same principles.

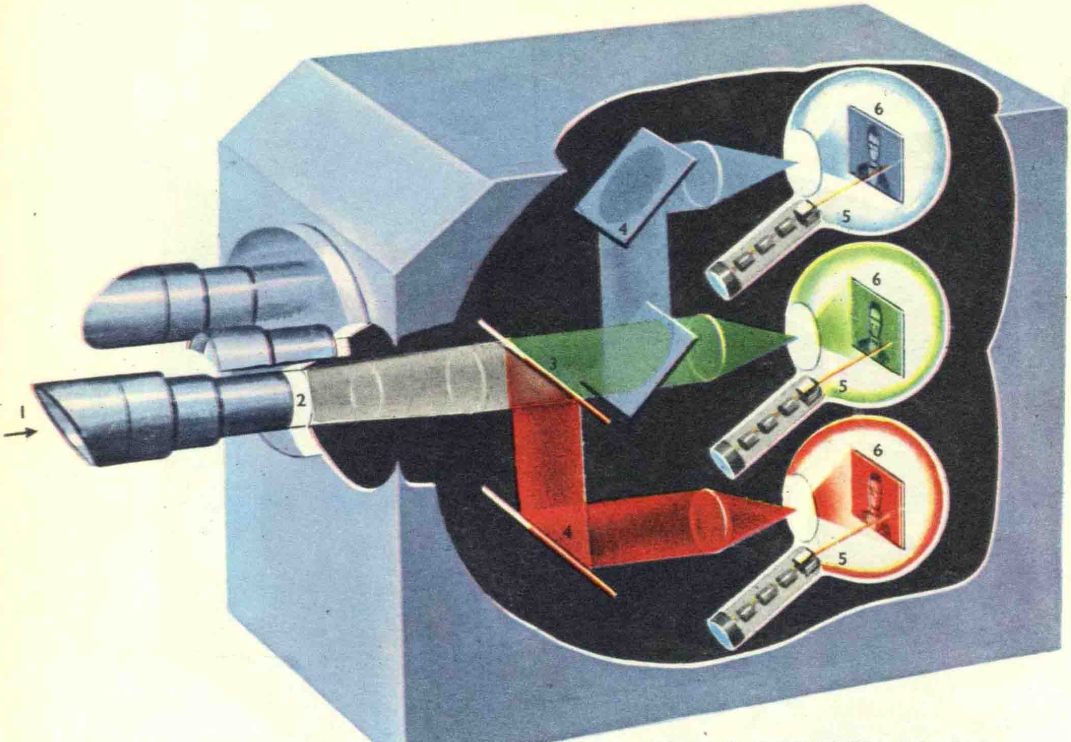
Placed at one end of a Cathode Ray Tube is a thin mica sheet which has millions of tiny spots of Caesium deposited on it. It is backed with a metal plate. If a picture being televised is focused on to the Caesium, the Caesium will give off electrons (a process known as the photo-electric effect) leaving the tiny spots of Caesium as small condensers with positive charges. The amount of charge is in proportion to the amount of light that was focused on to the spots of Caesium. A beam of electrons is made to scan line by line (just as you read this page) the plate on which the positive charges are a mosaic of the picture being viewed. The beam of electrons neutralises this charge causing an electric current to flow. The variations in this current are transmitted just as in radio.

At the receiving end a beam of electrons on a C.R.T. screen is made to form a " raster " or frame of these lines in sympathy with those being formed by the scanning of the mica plate in the camera tube. As these lines are traced the variations in current which were transmitted are applied to the control grid of the C.R.T. causing a brightening or darkening of the line being traced. A picture is then recreated identical to the one being televised in the studio.

TELEVISION PICTURE TUBES SHOWING PRINCIPLE OF SCANNING



Colour Television



1. LIGHT FROM OBJECT
2. LENS
3. HALF-SILVERED MIRRORS
4. REFLECTING MIRRORS
5. PICTURE TUBES
6. MOSAICS BEING SCANNED IN-STEP

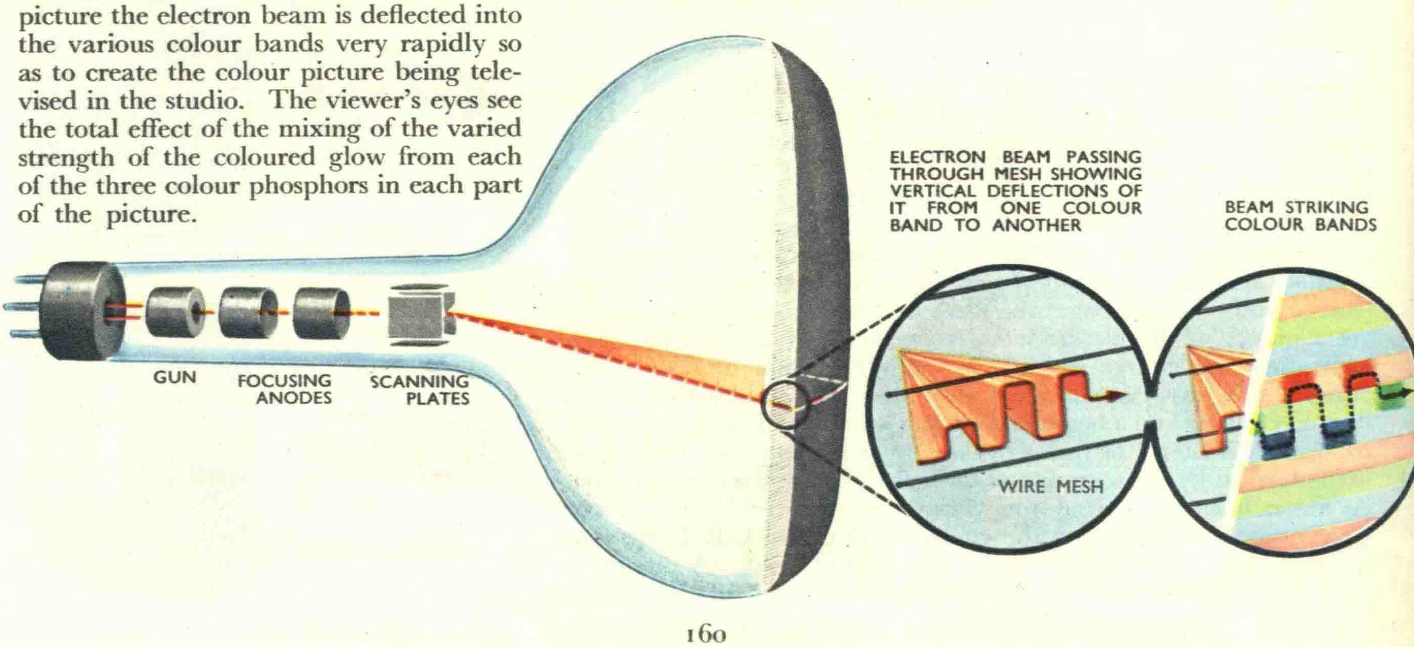
COLOUR TELEVISION CAMERA

Colour television is still in its infancy. Some systems have been made, mainly in America, and one or two experimental ones in Britain.

There are three primary colours, red, blue and green, from which all the others can be created by suitable mixing. The colour picture to be televised is viewed by a camera which has three camera tubes, one will respond to the red content of the picture, one to the blue content, and one to the green. Each of these is scanned by its own electron beam as already described for ordinary television, but they must be scanned together and in step with one another. The variations in current produced from the mica plates of the three camera tubes are transmitted.

In the receiving television set a special Cathode Ray Tube must be used to recreate the colour picture. One such tube has very fine horizontal bands of primary colour phosphors across the tube face. Behind this is placed a fine wire mesh which is aligned with the colour phosphor bands. The electron beam can be deflected on to any of the colour bands by applying suitable voltages to the wire mesh.

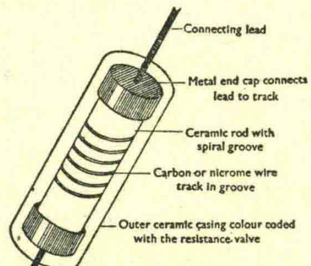
As the lines are traced to create the picture the electron beam is deflected into the various colour bands very rapidly so as to create the colour picture being televised in the studio. The viewer's eyes see the total effect of the mixing of the varied strength of the coloured glow from each of the three colour phosphors in each part of the picture.



ELECTRONICS

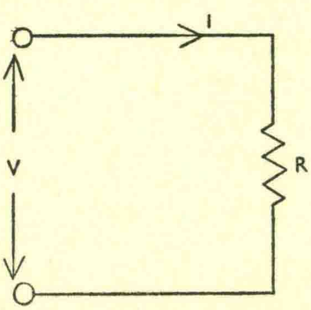
There are three major circuit components used in electronics; they are

1. RESISTOR



Resistor (actual size)

The relationship between voltage and currents is given by Ohm's Law (electricity, see p. 27). This law holds for both direct and alternating currents.

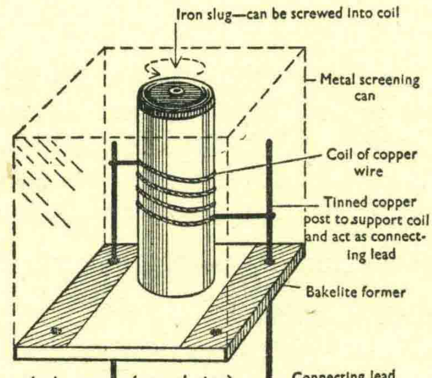


Voltage = Currents × Resistance
Volts = Amps × Ohms
$V = I \times R$

The resistance is a physical quality of a conductor. Its value in ohms does not depend on the frequency of the applied voltage. The range of voltage, current and resistance met with in practice varies from a millionth part to a million times.

1 Kilovolt (KV) = 1,000 volts (V) = 1,000,000 millivolts (mV) = 1,000,000,000 microvolts (μV).
1 Kiloamp (KA) = 1,000 amps (A) = 1,000,000 milliamps (mA) = 1,000,000,000 microamps (μA)
1 Megohm (MΩ) = 1,000 kilo-ohms (KΩ) = 1,000,000 ohms(Ω).

2. INDUCTOR



Inductor (actual size)

An inductor or coil has three major properties.

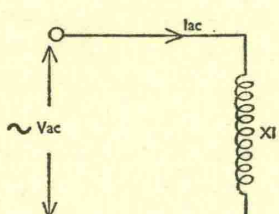
(a) It offers a Low resistance to Direct Current—Ohm's Law applies.

(b) It offers a High resistance (inductive reactance) to Alternating Current.

(c) The Alternating Current is Not in Phase* with the Alternating Voltage.

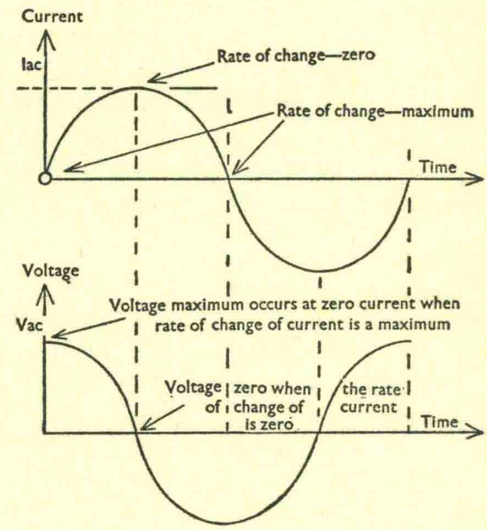
The coil's low DC resistance (R) depends only on the wire work.

The resistance (reactance) to alternating current depends on the coil itself (dimensions and number of turns) and the frequency of the alternating current. The higher the frequency, the higher the reactance.



Voltage = Current × Reactance
Volts = Amps × Ohms
$V_{ac} = I_{ac} \times X_L$
where $X_L = wL = 2\pi fL$; f = alternating frequency cycles/sec.; L = inductance in Henrys.

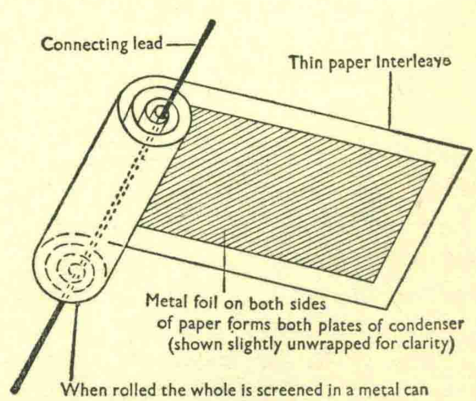
*Not in Phase *means that the alternating voltage and current are not in step at a given instant.* This arises because the voltage across a coil only exists if the magnetic field, and hence the current, is changing. The voltage across the coil is proportioned to the rate of change of current flowing.



One cycle of alternating current is shown. The voltage waveform Leads the current waveform by $\frac{1}{4}$ of a cycle.

1 Henry = 1,000 millihenrys (mH) = 1,000,000 microhenrys (μH).

3. CAPACITOR



Capacitor (actual size)

Like the inductor, it has three major properties:

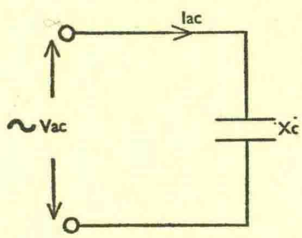
(a) It offers almost complete resistance to direct current (DC).

(b) It offers a low resistance (capacitive reactance) to alternating current.

(c) The alternating current is NOT IN PHASE* with the applied voltage.

The very high DC resistance of the capacitor is often called the leakage resistance and only a minute DC can flow through it.

The resistance (capacitive reactance) to alternating voltages depends on the capacitance (area of plates and distance apart) and the frequency. The higher the frequency the lower the resistance. For alternating voltages:



VOLTAGE = CURRENT × REACTANCE

VOLTS = AMPS × OHMS

Vac = Iac × Xc

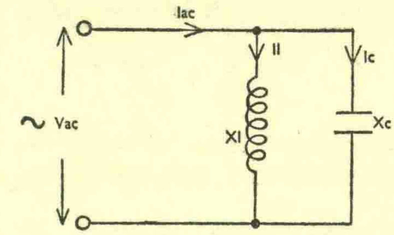
where $Xc = \frac{1}{wC} = \frac{1}{2\pi fC}$; f = alternating frequency cycles/sec.; C = capacitance in FARADS.

Units of capacitance:

1 Farad = 1,000,000 microfarads (μF) = 1,000,000,000,000 micro-microfarads ($\mu\mu$F).

* *A current will only be maintained if the voltage across the capacitor is changing. That is, the current is proportional to the rate of change of voltage. Because of this the voltage will not be in step with the current. In fact, as for the inductor, it is ¼ of a cycle out of PHASE. The voltage lags behind the current.*

TUNED CIRCUIT



$X_L = wL$; $X_c = \frac{1}{wC}$

The current Iac which flows in the circuit is composed of two currents: I_L through the conductor, and Ic through the capacitor.

1. At low frequencies wL is only a few ohms. $\frac{1}{wC}$ will be many hundreds of ohms.

Nearly all the current will flow through the inductor. The circuit behaves as a low resistance circuit to the applied voltage.

2. At high frequencies wL is many hundreds of ohms. $\frac{1}{wC}$ is only a few ohms.

Nearly all the current will flow through the capacitor. The circuit again behaves as one of low resistance to the applied voltage.

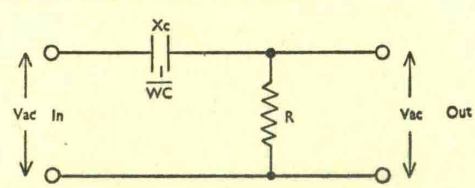
3. At medium frequencies wl will be comparable with $\frac{1}{wC}$. The resistance of the circuit to current flow is greatest when

$$wL = \frac{1}{wC};\ \text{i.e. } w = \frac{1}{\sqrt{LC}}$$

$$\text{or } f_o = \frac{1}{2\pi\sqrt{LC}}$$

This is termed the resonant frequency of the circuit; the current flow is at a minimum and the resistance is at a maximum.

RESISTANCE—CAPACITANCE NETWORK



This circuit is frequently used. In AC amplifiers it is used to couple one valve stage to the next. Firstly, the capacitor acts as a DC blocking device—it prevents DC from being fed from one stage to the next; secondly, it transfers the AC voltage. At a known frequency its reactance can be made very low compared with R so that nearly all the AC voltage is transferred. Thirdly, as long as the product RC remains the same, then the same fractions of AC voltage will always be transferred. This product is often referred to as the TIME CONSTANT of the circuit.

Worked examples

1. An inductor of 1 henry has a voltage of 50 volts at 100 cycles per second applied across it. Find the current flowing.

From this data we know that the current will also alternate at 100 cycles per second and will be ¼ of a cycle out of phase with the voltage. Its magnitude is given by

$$V = IwL \qquad w = 2\pi f = 2\pi.100 \simeq 600$$
$$V = 50$$
$$L = 1$$
$$\therefore 50 = 600I$$
$$\therefore I = \frac{50}{600} \text{ amps} \simeq 0.083\text{A} = 83 \text{ mA}$$

2. A voltage of 50 volts at 100 cycles per second is applied to the plates of a capacitor. Its capacitance is 1 farad. Find the current.

$$V = I\frac{1}{wC} \qquad V = 50$$
$$C = 1$$
$$\therefore 50 = I\frac{1}{600} \qquad w \simeq 600$$
$$\therefore I = 30{,}000 \text{ amps} = 30\text{KA at } 100 \text{ cycles/sec.}$$

3. A tuned circuit has a capacitance of 1 microfarad (μF) and an inductance of 100 microhenrys (μH). Find the resonant frequency.

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

$L = 100.10^{-6}$ henrys

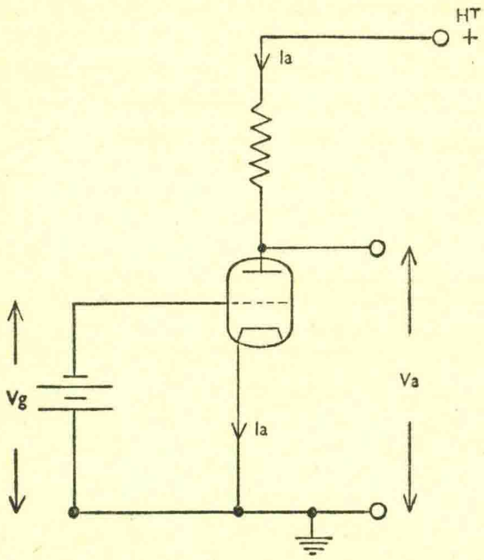
$C = 1.10^{-6}$ farads

$\therefore LC = 100.10^{-12} = 1.10^{-10}$

$f_o \simeq \dfrac{1}{6\sqrt{1.10^{-10}}} \simeq \dfrac{10^5}{6} \simeq$

16 kilocycles/second (Kc/s)

VALVE CHARACTERISTICS



The three factors which show how the valves operate are: (1) Anode voltage Va; 2. Anode current Ia; (3) Grid voltage Vg.

The way these three factors depend on one another is shown in the valve constants. These are:

1. Mutual conductance (g_m) (measured in mA/V)

   g_m = *small change in anode current* ÷ *small change in grid voltage consistent with the change in anode current.*

2. Internal resistance (r_a) (measured in KΩ)

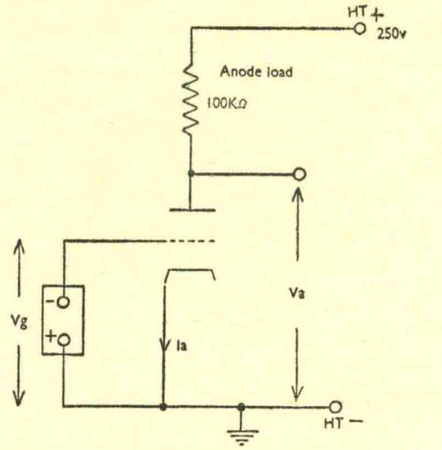
   r_a = *small change in anode voltage* ÷ *correspondingly small change in anode current.*

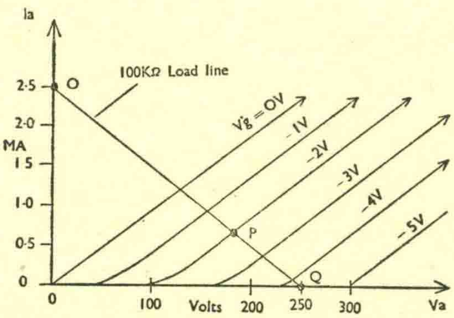
3. Amplification factor (μ)

   μ = *small change in anode voltage* ÷ *small change in grid voltage.*

These properties of the valve are best shown on graphs. These are supplied by valve manufacturers for particular valve types. An example is shown in the following diagram.

TRIODE





The valve characteristics show how Va varies with Ia for the valve in question. On this graph is drawn a line OPQ which shows how the valve will behave with the 100KΩ anode load. At any point on this line we have a definite Ia, Va and Vg. If Vg were to vary in any way between the Vg lines, then from the corresponding movement along this line we can read off the change in Ia and Va caused by the change in Vg. The valve characteristic curves are extremely useful for designing amplifiers, appreciating how they work and in finding faults in valve circuits.

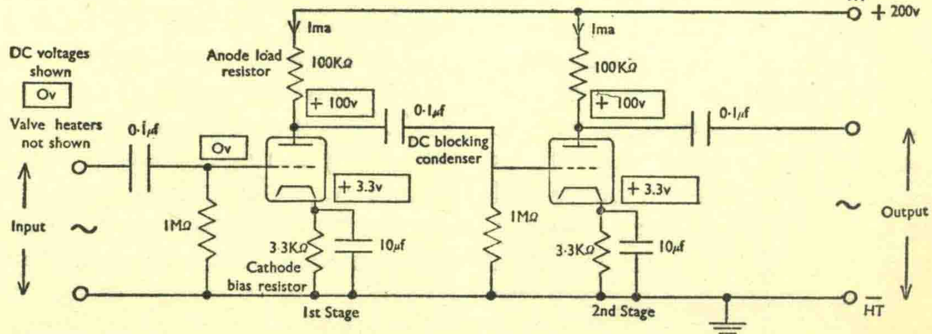
AMPLIFIERS

One of the major requirements in electronics is the amplification of either DC or AC voltages. We describe AC amplifiers here. DC amplifiers are generally similar except that the coupling and bypass capacitors are not required.

TRIODE VOLTAGE AMPLIFIER

Circuit Explanation

This is a typical radio amplifier. By this we mean it will amplify or have a frequency response from 10 cycles/sec. up to 20,000 cycles/sec. The HT is + 200V and the current taken by each valve is 1 mA. The voltage to be amplified is applied to the input; any voltage with a frequency higher than a few cycles/sec. will be transferred by the 0.1μf capacitor. The voltage is then amplified by the 1st stage about 30 times. The cathode circuit has a 3.3 KΩ cathode bias resistor which supplies a bias of 3.3V to the grid and ensures the valve operates correctly at the required anode current. This cathode resistor on its own would reduce the gain; it is therefore necessary to bypass this with the 10 μf capacitor, which effectively shorts the cathode to earth for AC voltages above a few cycles/sec. The amplified AC voltage from the anode of the 1st stage is passed by the DC blocking capacitor on to the next stage which is identical to the 1st stage, and is again amplified about 30 times. The overall amplification is therefore 900 times for the amplifier. The gain from a triode valve in most



circuits is nearly always equal to a characteristic known as the amplification factor (μ). This is quoted by valve manufacturers as a constant of the valve.

There are several important points to note about this amplifier.

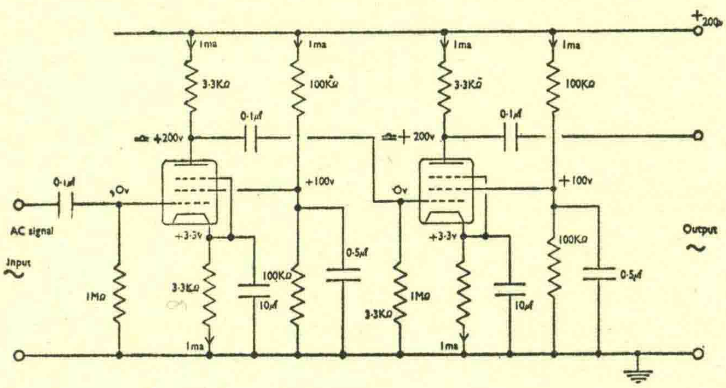
1. It requires hardly any power to operate the amplifier. The input only sees a load of 1 MΩ, which for 1 volt AC input would only be 1 μA.

2. The amplifier will not respond at frequencies below say 10 cycles per second. This is due to the RC combination of the input circuit, the coupling circuit between stages and the cathode biasing network.

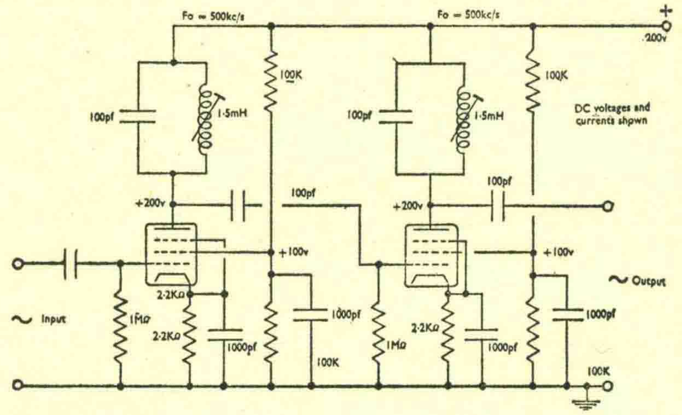
3. The amplifier will not respond to frequencies higher than say 20 Kc/s. This is due to the RC combination in the anode circuit comprising the anode load resistor and the stray capacitance to earth which bypasses any high frequency voltages to earth, thus reducing the gain at those frequencies.

4. Triodes have quite a large stray capacitance between anode and grid and the apparent capacitance which appears between grid and earth is very large and arises from an effect known as the MILLER EFFECT. Where a large frequency response is required pentode valves must be used, they do not suffer from this effect because the capacitance between anode and grid is much reduced and frequency responses up to 10 Mc/s can be easily achieved.

PENTODE VOLTAGE AMPLIFIER



TUNED CIRCUIT VOLTAGE AMPLIFIER



This amplifier is very similar to the triode amplifier already mentioned except for the fact that it has a frequency response from 10 c/s up to 10 Mc/s. Its response to low frequency has one more RC combination introduced at the screen grid. This is chosen so that it will have no effect above a few c/s. At the high frequency end of the response the anode load is chosen so that with the stray capacitance between anode and earth (about 5 pf for the pentode) the capacitance will only affect the response above 10 Mc/s. The amplifier has a gain of approximately 1,000. The gain from a single pentode is $g_m R_l$, where g_m is the mutual conductance (a constant for the valve) and R_l is the anode load. R_l can be varied over a large range from about 1 KΩ to 500 KΩ, though of course at the extremes the g_m will be reduced.

In the tuned circuit voltage amplifier (right) the anode loads of the conventional amplifier have been replaced with tuned circuits. The tuned circuit is designed so that the L and C will have a resonant frequency around 500 Kc/s. Adjustment to exactly 500 Kc/s is made by tuning the slug in the coil so as to change the "L" slightly to the required value. The amplifier will have an extremely high gain at 500 Kc/s, but because the resistance of the tuned circuits falls off very rapidly either side of 500 Kc/s so the gain will be considerably reduced. In fact the usable response may only be the band between 490 Kc/s and 510 Kc/s. Because of the relatively high frequency employed and the small usable response it is necessary to use quite small coupling capacities between stages and also quite small capacities by passing the screens and cathodes to earth.

FEEDBACK IN AMPLIFIERS

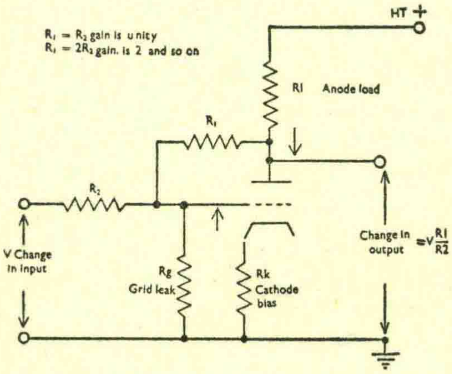
In order to build circuits to operate under given conditions it is often necessary to employ feedback. This is accomplished by feeding a fraction of the output from an amplifier back to its own input. If the feedback tends to reduce the signal at its input, then it is called NEGATIVE feedback. This has the effect of reducing the gain of an amplifier and thus making it more stable and less dependent on the characteristics of the valves used. This means it improves the performance of the amplifier. If the feedback tends to increase the signal at its input it is called POSITIVE feedback. This has the effect of increasing the gain of an amplifier and thus making it less stable. In fact important use is made of this property in the design of OSCILLATORS.

Example of Feedback

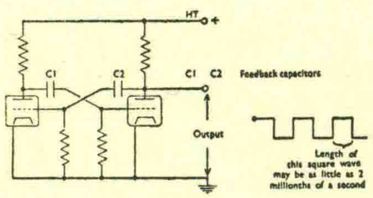
1. Summing amplifier

R1 feedback resistor (valve chosen so as not to "load" R1)

Remembering as the grid goes positive current flows and the anode goes negative as fraction of this voltage is fed back to the grid to reduce the input voltage, i.e. NEGATIVE feedback.



2. Multivibrator



As the name implies, the circuit multivibrates, giving a square wave output. As the circuit is switched on one of the valves will start to conduct; the drop in voltage at its anode is fed via C1 to the grid of the other valve. This valve amplifies the negative voltage, producing a positive gaining voltage at its anode which is fed via C2 back to the grid of the first valve. This is in sympathy with what is already happening in the first valve—that is, the feedback is positive. The amplifier is unstable and the net result is that the anode of the first valve will fall very rapidly to a point at which it "bottoms". The circuit will then stay in this state until the second valve starts to conduct, when a switchover will again occur. The amplifier produces a "square wave" output. An important use of multivibrators is their use as switches, to switch on and off very rapidly other circuits (e.g. computers).

ELECTRONIC CIRCUITS

It will be appreciated that by using resistors, capacitors, inductors and valves many novel circuits can be designed and these can be used in diverse ways to produce equipment for specific purposes. Many other components in the last decade have been developed and these are listed with explanations. One branch of electronics which requires special mention is COMPUTERS. This field is of much importance and its impact will probably be as great as, even if not greater than, that of the industrial revolution. Basically there are two types of computer: DIGITAL and ANALOGUE.

DIGITAL COMPUTERS

Perhaps the simplest of these is one with which every ancient Roman and modern Japanese schoolboy is familiar—the ABACUS. This consists of rows of beads which are threaded on to a wire frame. Simple arithmetic calculations are carried out by movement of the beads along the wire. Digital calculations are always characterised by operations on definite units. We are all familiar with the decade units system 0, 1, 2, 3, 4, 5, 6, 7, 8, 9. It has been shown mathematically, however, that a more economic use of units is attained if we use a binary system. This has only two units: 0, 1. It so happens that we can deal excellently with this system in electronic computers, for we need only two conditions:

0—represented when *no* current is flowing.

1—represented when *maximum* current is flowing.

This state of affairs can be realised by switching ON and OFF current through a valve, for example.

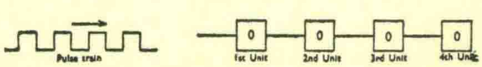
Why do we need electronic computers? The answer to this is simply speed of operation. For example, it takes time to move the beads along a frame—it takes time to move the mechanical parts in a calculating machine, but valves can be switched on and off in 1.10^{-9} seconds; that is, one thousand millionth part of a second.

It takes our brain several seconds to add two five-figure numbers together. A computer can add up to one hundred thousand units every second.

Problems in science occur which would take men several years to solve. A computer can solve the same problem in a matter of days. Predictions on the position, course and speed of missiles whilst in flight would be practically impossible without the aid of computers.

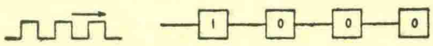
There is also another important factor. In the mechanical system the human brain is always in control and often errors can occur. In the electronic computer the computer itself has a "store" or "memory" where all the information relating to the impending problem is kept. Once the computer is set in motion, it carries out all the necessary operations in a well-disciplined manner and refers to its own "brain" or store for orders on what necessary steps to take in order to solve the problem; it is not dependent on the human brain once it is set to work.

How does an electronic computer count? Usually a train of electrical pulses are fed into the system containing a number of units connected together as shown.

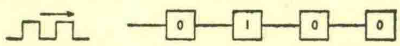


Each of these units contains a valve circuit and each circuit has two stable states—it is either switched OFF or ON. Initially all the units are switched off.

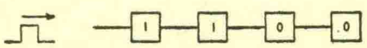
When the first pulse is fed in, the first unit is switched ON as shown, corresponding to the unit digit in the binary system.



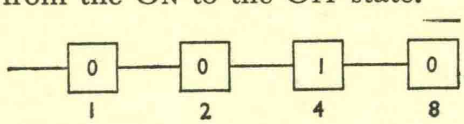
On receipt of a second pulse the first unit is switched off but in doing so it sends a pulse into the second unit (this is the same as carrying one in the decade system) and switches it on as shown.



On receipt of a third pulse the first unit is switched on again.



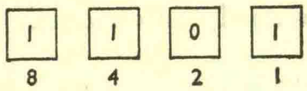
On receipt of the fourth and last pulse of the train the first unit is switched OFF; this then swtiches the second unit OFF, which then switches the third unit ON. The final state for the four pulses is then as shown. Observe that one unit can only switch on a following unit as itself is being cleared from the ON to the OFF state.



Note that the first unit contains the "ones", the second unit contains "twos", the third unit contains "fours" and so on.

We can deduce the binary code system.

In binary code



represents

$$8+4+0+1=13$$

We have seen how the unit stores can count the pulse trains; obviously we are limited to a certain maximum number we can count by the number of unit stores available.

For example, 32 such unit stores can count in binary up to 11, 111, 111, 111, 111, 111, 111, 111, 111, 111, 111 which represents the number 4,294,967,295.

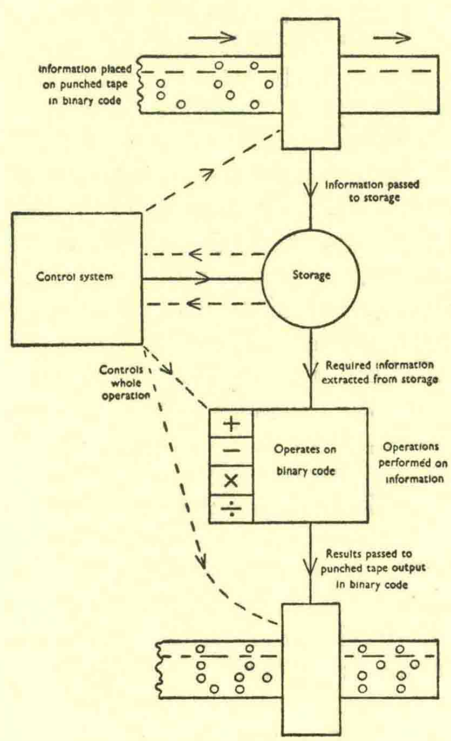
This is a phenomenal number for such a small number of unit stores. Once rules have been learnt, binary arithmetic is very similar to the decade system. Numbers can be added, subtracted, multiplied and so on. In order that these operations can be carried out the computer must have a store to hold the information and a control system to give it instructions.

A common store used is made of magnetic tape; small areas of magnetisation on the tape correspond to digits of the binary system.

For example, to multiply 712 by 64, 712 would be held in binary code on the tape in one store, 64 would be held in a similar store.

The control system would give instructions so that these numbers would be extracted from their "stores" and multiplied together.

The complete computer operation is shown diagrammatically.



ANALOGUE COMPUTERS

Briefly these are electronic devices which simulate or are analogous to a practical system. Unlike digital computers which deal with numbers or units, the analogue computer deals with quantities which are continually changing with time.

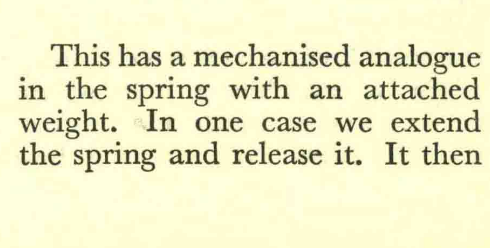
For example, suppose we wished to build a bridge across the English Channel. Before building it we would require to know how it would behave under such forces as wind, sea, and varying weight of traffic. An analogue computer could be set up to simulate this problem using not of course steel fabrications but electrical components chosen to represent them. By simply turning a few controls an operator in the computer room could study the behaviour of the electrical analogue of this bridge under the action of electrical forces representing the actual forces and could deduce whether the proposed bridge would be a safe practical proposition.

The advantages of such a computer are immediately obvious. At small cost we can build an electrical model and from it deduce how the actual construction would behave under known conditions.

How does the analogue computer work?

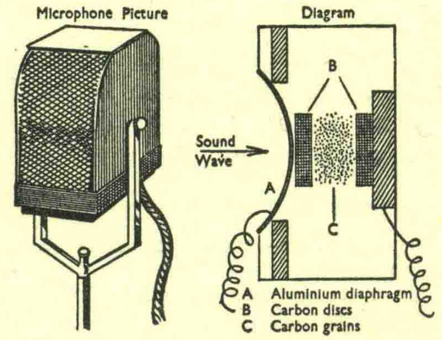
To answer this question we must delve into the world of mathematics. If we can find a mathematical law which defines how a given system behaves, then we can build an electrical equivalent to this system which obeys the same mathematical laws.

For example, we considered in an earlier section the oscillatory nature of the current in an inductor and capacitor.



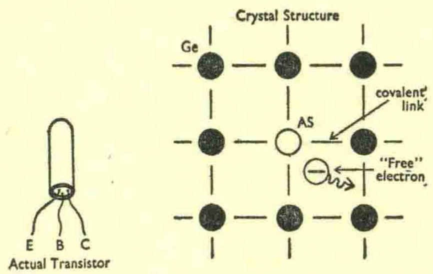
This has a mechanised analogue in the spring with an attached weight. In one case we extend the spring and release it. It then

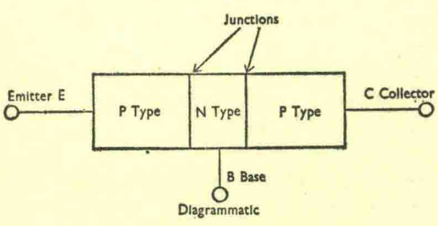
moves up and down in a rhythmic manner until it finally comes to rest. In the electrical case we place a surplus charge of electricity on the condenser plates. The charge then moves from one plate to the other in a rhythmic manner until it is finally dissipated as heat in the resistance of the circuit. It only remains to be said that both the systems obey the same mathematical laws. It is perhaps fortunate that by the simple arrangement of inductors, capacitors and resistors in electrical circuits we can simulate the mathematical laws obeyed by practically all the mechanical systems. Thus an analogue computer can be constructed to simulate given engineering, scientific or mathematical problems.



A sound wave causes the diaphragm to move rhythmically which compresses the carbon grains. The resulting rhythmic variation in resistance of the carbon grains can be utilised to provide a voltage directly related to the sound wave.

TRANSISTOR





Similar in operation to the triode valve, except here conduction is achieved by the movement of electronic charge within a crystal structure and amplification is achieved by controlling this current flow by application of voltage to the crystal structures. The crystal structure is of two main types:

N TYPE—conduction by negative charge.

P TYPE—conduction by positive charge.

Silicon or germanium are normally used. In the pure state they are electrically neutral. They can, however, be "doped" in minute quantity with such impurities as arsenic (N type) or aluminium (P type). The arsenic atom displaces one of the silicon atoms in the crystal structure and after forming the necessary covalent links is left with a free electron for conduction. Conduction is controlled by the application of voltages. The distinct advantages of transistors over valves are: (1) compactness and smallness in size; (2) no heater voltages required; (3) wide applications, e.g. they can carry 1,000 amps when only $\frac{1}{2}$ inch long. A comparable valve would be many feet long and would require extensive cooling.

MAGNETIC TAPE RECORDING

Variations in current from a microphone are used to produce small variations in magnetisation of a "record head" in a tape recorder past which the magnetic tape is moving at a steady speed. The magnetic tape consists of a plastic tape in which are emulsified fine magnetic particles which have been carefully aligned like small magnets. As the tape passes the RECORD head the variations in magnetisation move these very small magnets. The collected tape thus has a recording imposed on it. If this tape is then passed by a "play back" head at a constant speed, the state of its magnetisation will cause a small AC voltage to be induced in the coil around this head. After amplification this can be made to drive a loudspeaker faithfully reproducing the recorded sound.

VIDEO TAPE RECORDING

The electrical variations corresponding to the transmitted pictures in television can also be recorded on magnetic tape. A television programme can thus be recorded and played back at will.

PHOTOELECTRIC EMISSION

Some metallic surfaces can liberate electrons when exposed to light. Most transistors are photoelectrically sensitive.

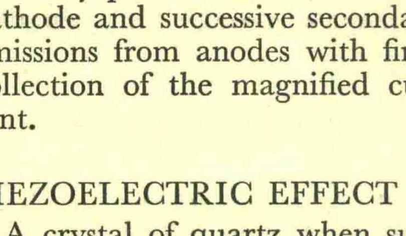
Photocells—detectors of light radiation. Photomultipliers—current multiplication (10^6) is achieved by photon emission from a cathode and successive secondary emissions from anodes with final collection of the magnified current.

PIEZOELECTRIC EFFECT

A crystal of quartz when subjected to a mechanical strain produces a charge at its focus. If the strain is varied an AC voltage appears across the crystal. Conversely, if an AC voltage is applied to the crystal it will vibrate.

Used in oscillators, hydrophones, ultrasonic generators, and pick-ups.

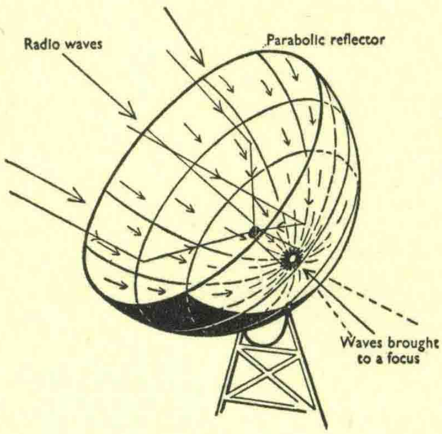
TRANSFORMER



Device for conversion of AC power to differing voltage levels. Basically a toroid of soft iron with a primary and secondary coil

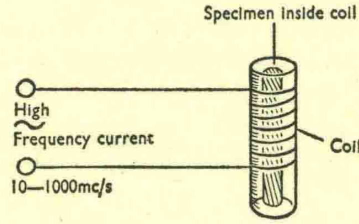
wound on it, the AC voltage in the primary produces a varying magnetic flux in the iron. This links with the secondary, producing a voltage of a value dependent on the coils' ratio. The voltage can be stepped up or stepped down.

RADIO TELESCOPE



Radio waves originating in outer space are collected by the telescope's aerial. This enables astronomers to study distant galaxies which cannot be detected by the optical telescope.

RADIO FREQUENCY HEATING



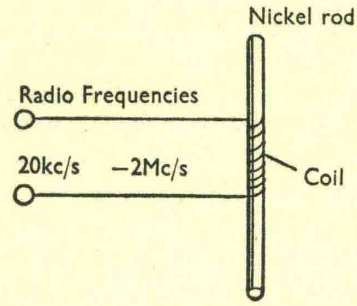
Radio frequency field vibrates the atoms of the specimen at an extremely fast rate. They become hot and the specimen may even melt.

Applications—Radio frequency ovens, to relieve muscular pains, to heat joints for glueing, "getting" of valves.

ULTRASONIC FREQUENCY DEVICES

Radio frequency field causes nickel rod to expand and contract (magnetostriction).

Applications—Ultrasonic drills—engineering and dentistry. ASDIC detectors for hydrography and fisheries. Fabric cleaning. Computers—storage devices.



ERNIE (Electronic Random Number Indicator)

Used in Premium Bond draws in the United Kingdom.

Principle—Random pulses are displayed as numbers on decatrons (cold cathode discharge tube arranged so the gas can be made to glow in any of ten different areas representing the numbers).

Glossary

A.V.C. Automatic Volume Control. In radio receivers some of the radio signal is rectified to DC, which is used to bias the valves in the early stages, thus maintaining the volume at a constant level.

Aerial (Antenna) Device for conversion of wireless waves to electrical impulses.

Ammeter Instrument in which angle or deflection of a pointer is proportional to the electrical current flowing.

Amplifier Device containing valves. Purpose is to increase in magnitude the electrical energy supplied to it.

Amplitude modulation The most common type of radio signal. A steady radio frequency (the "carrier") is varied in strength ("amplitude") in step with the variation of the audio (voice) signal it is desired to broadcast. The AM radio receiver separates (detects) this variation of amplitude and so reproduces the broadcast audio signal in the loudspeaker.

Bias The voltage applied between grid and cathode of a valve to limit the current flow.

Carrier The wireless wave which carries the information.

Decibel A logarithmic scale often used to denote the gain of an amplifier.

Dielectric The insulating medium (air, oil, paper, mica are common ones) between the plates of a condenser. Increases the capacitance.

Distortion Occurs in many forms in electronic devices. Usually expresses the departure from the expected result of waveform.

Feedback Method of stabilising amplifiers.

Filter Method of separating differing frequencies.

Frequency modulation A comparatively recent development in radio broadcasting. The *frequency* of the carrier is varied by the frequencies of the audio signal. Special valve circuits produce output varying according to the frequency variation. FM gives a much more accurate reproduction of the audio signal broadcast than AM.

"Getter" Material (magnesium) for excluding the last traces of gas from a thermionic valve.

Ground The earth to which the common line is connected.

Harmonics The various frequencies which are simple multiples of a fixed frequency or fundamental.

"Hum" Usually associated with the 50 c/s mains supply. Sensitive amplifiers easily "pick up" hum, and special precautions must be taken to prevent this.

Modulation Process by which information (modulation) is impressed on the carrier wave.

Motorboating Undesirable feedback at low frequencies causing unwanted oscillation.

Neon-tube Gas discharge tube used as voltage regulator.

Noise Appears as random variations in current in electronic circuits.

Thermal noise—caused by temperature change in components.

Shot noise and Partition noise—variation in current through valves.

Flicker noise—irregularities in the cathode surface.

Microphony—mechanical vibration of electrode structures.

High frequency noises—in valves when transit time of electrons is comparable with frequency to be amplified.

Ohmmeter Instrument to measure resistance values.

Oscillator Device for generation of fixed frequencies.

Q Expresses ratio in a tuned circuit which determines the bandwidth of the circuit.

Rectifiers Device for conversion of AC to DC.

Relay Magnetic device. Electrical current causes a magnetic attraction between a fixed and moving part. The moving part carries contacts which can either close or open several external circuits.

Signal generator Instrument to produce a wide range of frequencies. These can be used to test and align receivers.

Signal and noise ratio This expresses the "goodness" of a receiver and is dependent on atmospheric conditions and the design of the receiver.

Tuning indicator A glass valve which casts nearly overlapping green shadows. The receiver is usually "in tune" when the two shadows nearly meet.

Valve voltmeter A very high input resistance voltmeter.

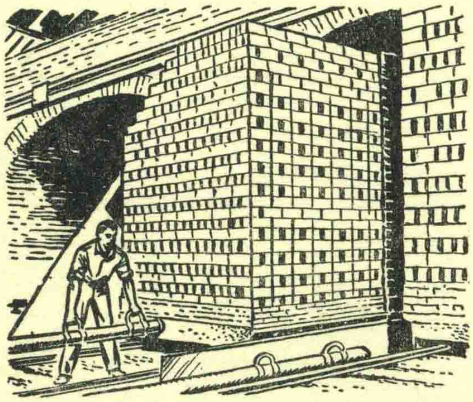
Industrial Processes

Though in earlier times men could exist largely by their own efforts, and needed only a few skills for their own personal use, the picture today has changed a good deal. It would be impossible for us to live our lives in the way we do without a vast number of industrial processes, carried out in general by other people. Only in this way can we obtain the goods we need.

A glance round any room will provide a whole host of instances of the industrial processes on which our way of life depends. Furniture, textiles, wallpaper, crockery, cutlery, carpets . . . the list is endless. All these products have received the specialised attention of scientists and technologists, who have combined new ideas with the traditional skills handed down through generations. Below are listed a few notes on some of the more important manufacturing processes which help to make our lives what they are today.

BRICKS

The clay used for making bricks is found on the beds of dried-up lakes and streams. It is dug out by mechanical excavators, finely ground under rollers, sieved to remove any large particles, and damped to give it the correct amount of moisture. Moulds, sprinkled inside with sand or water to prevent the clay sticking, are used to make individual bricks by hand. When they are made by machine a long band of clay is forced through a hole and cut to the correct size by wires. Finally the bricks are dried, either out of doors or in an oven, before being "fired"—that is, being subjected to a fierce heat in a kiln. Bricks are oblong in shape so that they may be overlapped when laid to provide a strong support for the burden they have to bear.

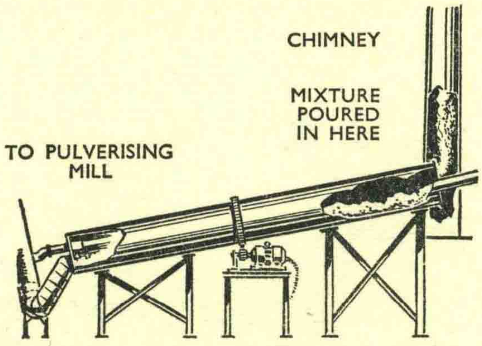


Putting bricks into a kiln for firing.

CEMENT

Cement is made from a mixture of clay, chalk and limestone. These substances are mixed with water into a cream-like substance called slurry. The slurry is then burned in a revolving steel kiln at a high temperature. At the end of this process all that remains of the slurry is a hot clinker which is ground to make the cement powder.

Cement is used either as mortar or as concrete. To make mortar the dry powder is mixed with sand and water and placed between bricks where it sets hard, binding



Burning the slurry in a revolving steel kiln to make cement.

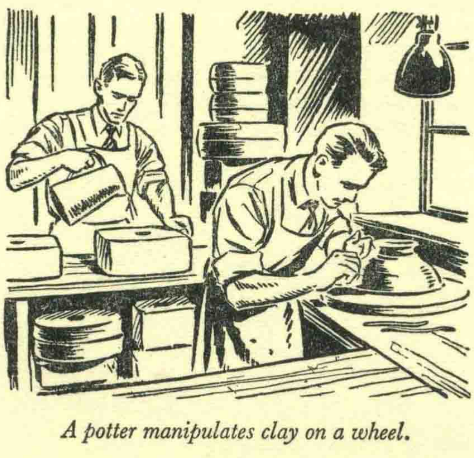
them firmly together. For concrete bulkier materials such as stones or gravel are added. This sets so hard that it has almost replaced stone which is more costly and less manageable.

EARTHENWARE

Ceramics are generally classified in four main groups: earthenware, china, stoneware and porcelain. Earthenware is by far the largest class and it includes most domestic crockery, much of which is wrongly called china.

The basic raw material of the industry is clay, which may be common clay which occurs in Staffordshire or the china clay (kaolin) found in Cornwall. In the manufacture of earthenware the clay is weathered and mixed with ground flint and feldspar. It is then mechanically mixed with water, pressed to remove excess water, and passed through a mill which extrudes large portions of the solid clay through a nozzle. It is in this form that a thrower cleverly manipulates the lumps of clay into any desired shape on a revolving wheel.

The tendency is for this craft method to be replaced in all mass-production work by semi-mechanical methods of moulding the clay. After shaping and drying, decoration can be applied either by hand or by printing from engraved copper. Since earthenware has a dull porous surface, it is always

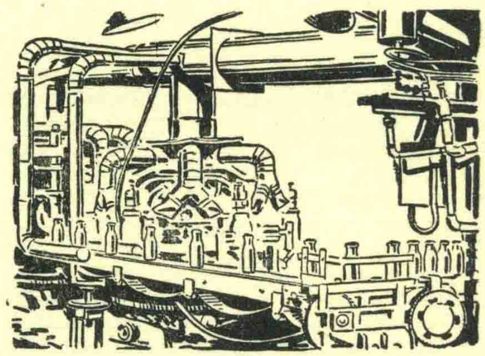


A potter manipulates clay on a wheel.

necessary to glaze it before firing in the kiln. The present trend is towards continuous kilns where small trucks laden with moulded ware move slowly through a heated tunnel. The temperature of firing is in the region of 1,100°C. and the process may take several days.

GLASS

Glass is not one material, but a range of hundreds of materials whose properties can be controlled by a choice of ingredients. The most important raw material for glass making is sand of high purity. Other ingredients include soda ash (sodium carbonate), limestone (calcium carbonate), saltcake (sodium sulphate), feldspar, borax, lead oxide and potash (potassium carbonate). The raw materials are first weighed and mixed in the correct proportions. Then by melting at temperatures between 1,300°C. and 1,500°C. the mixture is turned into glass. Tank furnaces may hold up to a thousand tons of glass where the production is large, mechanical and continuous. On the other hand, pot furnaces, only holding up to two tons, would be used for smaller batch production of different types of glass. Hand methods of shaping glass have given way first to hand-operated machines and finally to fully automatic machines which give us most of today's sheet glass, bottles, bulbs and all kinds of pressed and blown ware.

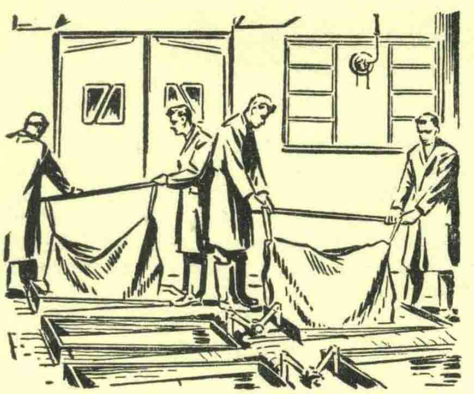


Making glass milk bottles by machine.

The final process in glass making is annealing to remove any internal stresses due to different cooling rates in different parts of the glass. The articles are reheated and then cooled slowly in an annealing furnace.

LEATHER

Leather is manufactured from the hides and skins of certain animals, especially cattle, sheep, calves, pigs and also rarer animals including reptiles. The main process involved is tanning, which converts the skin into a material which under ordinary conditions does not putrefy. This process is preceded by several preparatory operations including washing and de-hairing. There are two main methods of tanning. Vegetable tanning, with extracts from certain trees, is normally carried out on heavy leathers and may take three to four months to complete. Chrome tanning, with



Dipping sheets of leather into vats during the tanning process.

solutions of chromium salts, is used mainly for light leathers, and is a much quicker process. A number of finishing processes may follow, including dyeing, and in the case of shoe under-leathers a rolling process to harden the material.

MARGARINE

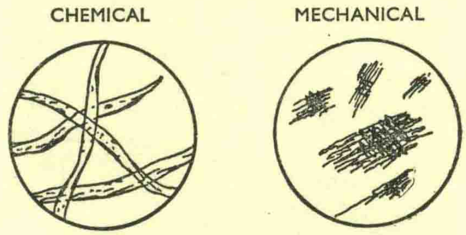
Margarine is made largely from vegetable oils obtained from such things as soya beans, ground nuts, cotton seed, sunflower seed, coconut palm and the oil palm. The use of these vegetable oils in margarine was only made possible early in this century when the process of hydrogenation was discovered. The process consists of passing hydrogen through the liquid oils in the presence of nickel, and its effect is to harden a sufficient portion to give a conveniently firm margarine.

In the "churn drum" method of margarine manufacture, the emulsion of oil, fats and milk is made in churns, the vitamins A and D are added, and the mixture passed to cooling drums. After this very low temperature treatment, the margarine is given time to recover before the next process of kneading. In this process the mixture is passed through a system of three pairs of granite rollers, closely spaced and rotating at different speeds. After a second resting period the margarine is finally blended and packed. The older method is being steadily replaced by the "rotator" method, in which all the above operations are combined into one continuous process allowing better control and higher standards of hygiene.

PAPER

Paper is a compact web of fibres, the basis of which is the material called cellulose. The fibres most used are those obtained from wood pulp, but esparto grass, straw, and rags are also of some importance. Wood does not consist entirely of the useful papermaking fibres, so these have to be extracted in some way.

The different methods of extraction give us the various types of wood pulp. "Mechanical wood pulp" is produced simply by removing the bark from the logs and grinding them in water to a pulp. This drastic treatment produces a pulp, with short cellulose fibres, which still contains a good deal of non-fibrous material. Obviously this

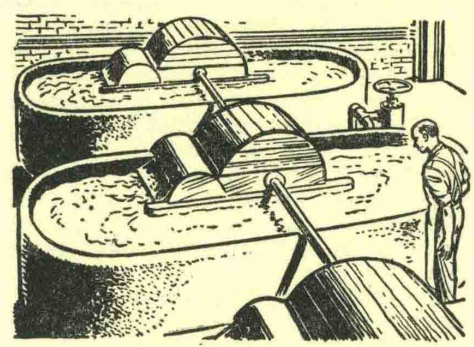


Two kinds of paper pulp seen under a high-powered microscope.

will not produce a strong paper. Newsprint, on which newspapers are printed, is largely manufactured from mechanical wood pulp.

Several chemical methods exist for extracting the papermaking fibres from wood. These methods have a better chance of preserving the fibre length and of removing the non-fibrous portions. Chemical wood pulps are used for making strong papers like the brown Kraft used for wrapping purposes.

The key stage in papermaking is in the "beater". Here the pulp, suspended in a large amount of water, circulates round an oval-shaped tank and is forced between a fixed bed of knives and the bars of a revolving roller. This splits and frays the ends of the fibres so that they will knit together more easily on the papermaking machine.



Pulp being blended in the paper beaters.

It is in the beater that different pulps are blended together in the correct proportions, and other materials like fillers, size, and colouring matters are added. China clay is frequently used as the filler. Its fine white particles fill the spaces between the lattice of fibres and make a paper smoother and more opaque.

From the beater the pulp passes through filters and then on to the "wet end" of the actual papermaking machine. At this stage the mixture may be as much as ninety-eight per cent water. It flows first on to a moving wire frame of fine mesh. The water tends to filter through this mesh and the side-to-side vibrating action of the frame helps to matt the fibres together. Before leaving the wire the soggy web of fibres passes over suction boxes which draw out more of the water. From the wire the paper travels on to an endless felt blanket which presses it against heavy rollers, forcing out still more of the water. At this point the paper has gained sufficient strength to support its own weight. From that point on the web passes through a long system of drying rollers and is finally reeled up at the dry end of the machine.

Paper boards of greater thickness than normal paper are made on a different type of machine, although the principles of working are much the same as that of the Fourdrinier machine which we have described.

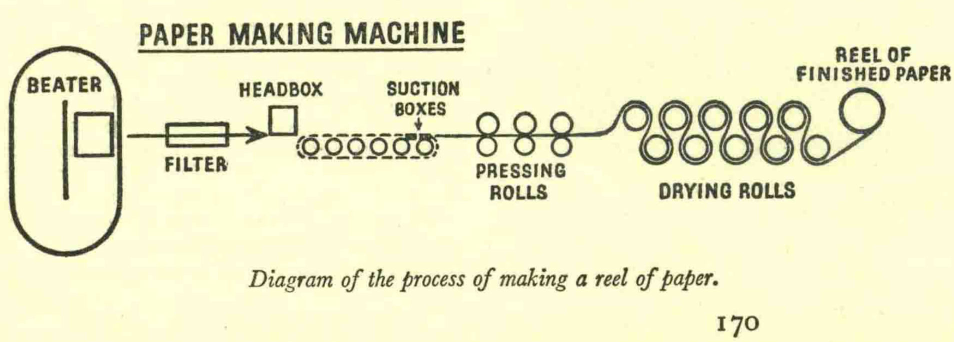
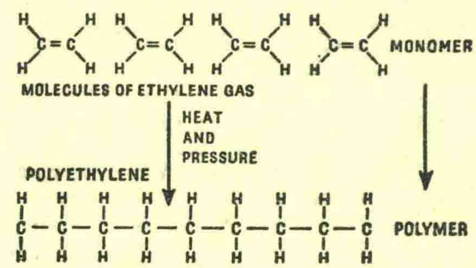


Diagram of the process of making a reel of paper.

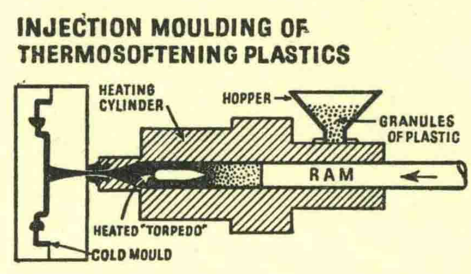
PLASTICS

Plastics are materials which at some stage in their manufacture are able to be shaped and moulded by heat, pressure or both.



The process of building up or 'synthesising' polymers from monomers. In this example polyethylene is produced.

Most plastics are polymers—that is to say, they have molecules consisting of long chains of atoms which have been built up by the combination of simple molecules or monomers. For example, polythene or polyethylene is a polymer formed from the monomer ethylene, a gas which can be obtained from

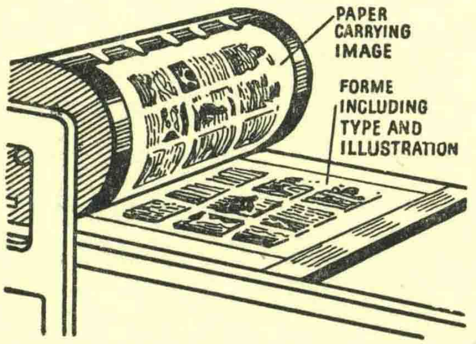


petroleum. If ethylene is subjected to high temperature and pressure, it combines with itself to form a long chain molecule.

Polythene is an example of a thermosoftening plastic, i.e. one which can be softened and reshaped indefinitely under the influence of heat and pressure. A second group which includes "bakelite" are called the thermo-hardening plastics, since once they have been moulded under heat and pressure to a solid they cannot be re-softened.

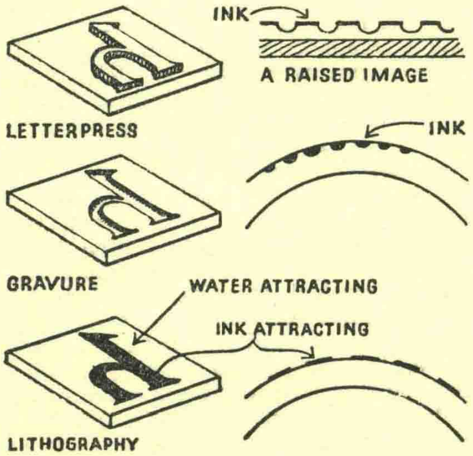
PRINTING

The aim of the printer is to produce economically a permanent image of type or illustration on some base material. This material is usually paper or paperboard, but it may also be tinplate, plastic film, textile or some other material. The image is produced with an ink which consists of a colouring matter bound with a resin. The ink



LETTERPRESS MACHINE

is usually liquid or semi-liquid on the printing machine and by some means is converted into a solid on the paper. Thus the image on the paper will be a colouring matter embedded in a film of solid resin which will bond it firmly to the surface and protect it from damage during its lifetime. The ink is transferred from a printing surface which is made from metal alloy, or occasionally from some plastic material. It is the nature of this printing surface which is the point of greatest difference between the three great divisions of the printing industry, namely: Letterpress, Gravure, and Lithography.



Diagrams showing the main differences between the three printing processes.

LETTERPRESS PRINTING

Letterpress is the oldest of the printing processes and it remains very important today. It is used in producing newspapers, most books, and a great deal of general printing matter. The metal image stands up in relief and carries an ink which is somewhat thicker than butter. When this surface is pressed against paper the ink transfers from the raised areas to give a clean, sharp impression. Normally copper or zinc is used to make the printing surface for illustrations, and an alloy of lead, tin and antimony for type.

GRAVURE PRINTING

Gravure printing is carried out from a metal printing surface which is the reverse of that used for letterpress. This time the image areas which carry the ink are small cells in the plate. The consistency of a gravure ink is nearer to that of milk than of butter. When the copper printing plate is pressed against the paper, the ink is drawn out of the cells to give a keyed image. Gravure is used almost exclusively for large circulation magazines, and extensively on packaging materials.

LITHOGRAPHY

The principle of lithography could be described as being in between that of letterpress and gravure, for the image and non-image areas of the printing surface are in the same plane. The process depends upon the fact that grease and water repel one another. The image is made grease-attracting and the non-image water-attracting or grease-repellent. On the printing press, the flexible printing plate, wrapped round a cylinder, first passes through a system of dampening rollers, when a film of water is transferred to all non-image areas but repelled by all the grease-attracting image areas. The plate then passes through an inking system, and the greasy ink transfers only to the image areas, being repelled wherever there is water. Lithographic ink has a similar consistency to letterpress ink. In direct lithography the inked-up plate is pressed against the paper. In offset lithography, which is now more important than the direct method, the image is transferred via a cylinder carrying a rubber blanket. A lithographic plate is made from zinc or aluminium. The process has become very popular in packaging, book printing, tin-box printing and office printing.

PLATE MANUFACTURE

The printing surface in letterpress machines usually includes type matter. This can be prepared by hand from the individual letters but often it is composed mechanically on monotype, linotype or similar machines. From a keyboard message the appropriate type is cast from molten alloy automatically.

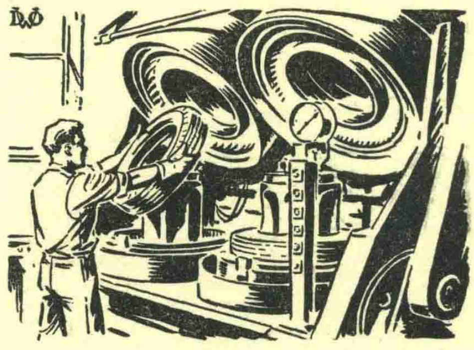
The illustration blocks in letterpress and nearly all lithographic and gravure plates are prepared photographically. The principle used is basically the same in all three processes. The metal plate is coated with a light sensitive material, and exposed to a powerful arc lamp through a photographic positive or negative of the image. In the areas where light is able to get through the photograph, the coating is hardened and loses its solubility in water. The actual amount of hardening is proportional to the amount of light getting through. After this exposure, the unhardened areas can be washed away with water, leaving the metal bare in these places. The plate can now be etched with an acid or acid salt, which will be able to attack only the parts which are unprotected by the hardened coating. In this way an image on the metal is obtained from a photographic image. Although the principle described is common to the three processes, the actual methods and materials used vary considerably.

A compositor 'locks up' the type for printing.

RUBBER

Our source of natural rubber is latex, the milky juice of the rubber tree. Latex is a colloidal suspension of hydrocarbon polymers, and the first stage in rubber production is to further polymerise and coagulate these hydrocarbons. This gives us raw rubber, a sticky material of limited usefulness. Almost all rubber products are made by mixing raw rubber with other materials like carbon black and zinc oxide, and then vulcanising in moulds by heating with sulphur.

Synthetic rubbers are man-made polymers designed to follow closely the molecular structure and hence the properties of natural rubber. For example, Buna S is prepared from butadiene and styrene, both of which can be obtained from petroleum.



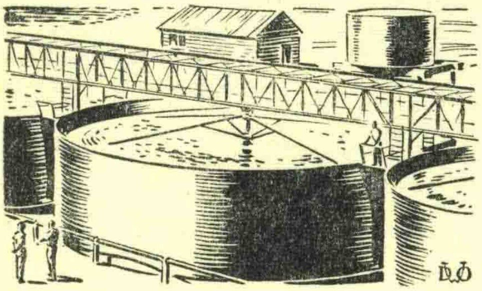
Moulding rubber tyres for the motor vehicle industry.

SILVER

Silver is a metal which has been used from the earliest times to make both useful objects, such as drinking vessels, and ornamentations. Our ancestors, who found it in a nearly pure state, discovered that it was easy to work, as well as pleasing to the eye. For its more practical uses today another metal (e.g. copper) is added to strengthen it. "Sterling" silver consists of 925 parts of silver to 75 parts of copper (similarly 18 carat gold is 18 parts gold and 6 parts copper).

Both gold and silver are worked in the same way. First the metal is thoroughly cleaned and softened by immersing it in a bath of warm, diluted sulphuric acid or by heating it. Then a piece of metal of the required depth and size is cut out and hammered into shape on a steel arm, being heated at frequent intervals to keep it soft enough to be worked. Small parts of an object, such as the spout or handle of a tea-pot, are fashioned separately and then soldered on to the main body.

The finished work has a rough, dull surface which is smoothed by beating it with a flat-faced hammer, and polished with a special stone and a mixture of charcoal and oil.

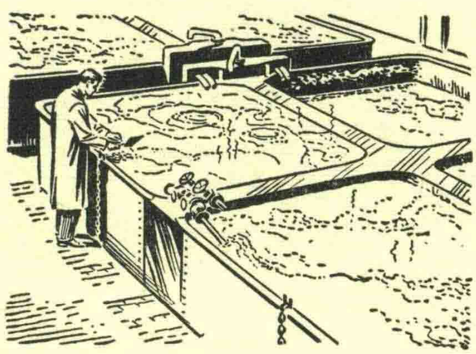


Refining silver in giant tanks of cyanide.

SOAP

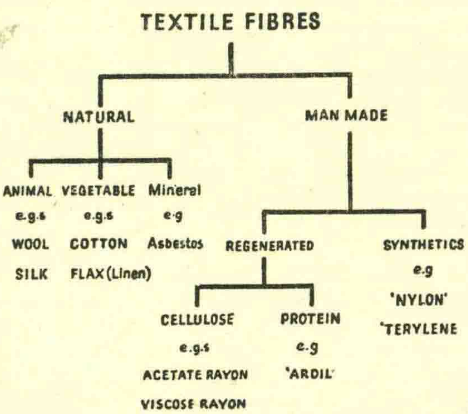
The main constituent of soap is some form of oil or fat which may come from one of many different sources, such as bones, olive, palm or whale oil, linseeds, cotton seeds, or coconuts.

Potash or caustic soda, and sometimes a combination of the two, is added to the oil, and when this mixture is boiled in large pans heated by steam pipes, a brown liquid is produced containing glycerine and soap. The soap rises to the surface of the liquid where it is run off and allowed to cool and harden. The glycerine is recovered, to be used as a raw material for nitro-glycerine. The soap is moulded or cut to the shape required, and in some cases scented.



Heating the mixture to produce soap.

TEXTILES



Until the 20th century all clothing was produced from four natural fibres. These were the animal fibres wool and silk, and the vegetable fibres cotton and flax. Today, in addition to these natural fibres (which remain very important) we have a large group of man-made textile fibres. This new group can be divided into the rayons, which are produced by modifying natural cellulose materials like wood, and the synthetics which are built up from simple chemicals derived from coal or petroleum.

Any fibre, whether it is natural or man-made, has to pass through a complicated series of processes before it becomes a useful article of clothing. Below are listed some of the more important of these.

Scouring The fibre is fed into a machine which blends it and opens it.

Combing The fibres are straightened, and the short ones removed.

Spinning The fibres are joined together by twisting, producing yarn.

Weaving The yarn is woven into cloth.

Dyeing The wool may be dyed in the cloth form or at some earlier stage of manufacture. It is steeped in a solution in water of a special wool dye for an hour or more. The temperature is varied during this time and agitation provided by moving either the wool, the dye liquor or both.

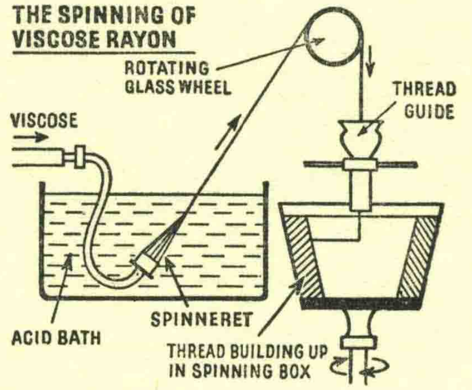
Milling The controlled felting of cloth made by the woollen process.

Pressing Machines are used to press the cloth before it is sent out to the tailors or retailers.

Many of the operations which have been outlined in the processing of wool are common to the manufacture of all textile fibres. On the other hand, due to their different origins and properties, cotton, linen, silk, and the man-made fibres require some of these processes to be modified and special operations to be added. Thus cotton, which is a seed hair, has first to be separated from the reed in a process called "ginning". Flax fibres are situated in the inner bark of the stem of the flax plant and the first process in linen manufacture is called "retting", where the outer bark is allowed to rot, so that a breaking process can separate it from the useful fibres. Silk consists of the twin filaments extruded by the silk worm. Since these filaments are bound together with a gum, it is necessary to remove all or part of it with a soap solution.

VISCOSE RAYON

Viscose and acetate rayons fall into the group of textile fibres which are regenerated forms of natural cellulose. The raw material for viscose rayon is wood pulp. The purified pulp is ground with sodium hydroxide and then mixed with carbon disulphide to form a yellowish-brown substance called cellulose xanthate. This dissolves in dilute sodium hydroxide to give a thick syrupy solution called viscose. After filtering and ageing, the solution is forced through the minute holes of a spinneret into an acid bath. The cellulose is precipitated again by the acid, in the form of fine threads which are drawn up out of the bath and over a rotating glass wheel. From the wheel the filaments pass down into an open spinning pot revolving at very high speed.

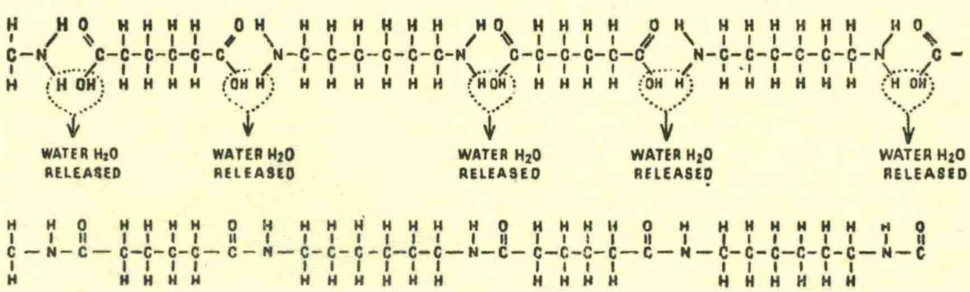


The yarn must finally be washed free of acid. The regenerated fibres can be produced as long continuous fibres, or they can be cut to short lengths. If the viscose solution is forced through a narrow slit instead of through fine holes the result is the film we know as Cellophane.

SYNTHETIC FIBRES

Synthetic fibres consist of large molecules with long chains of atoms which have been built up from quite simple molecules with relatively few atoms. The most famous synthetic fire is nylon, discovered in 1938. One type of nylon is made from adipic acid and hexamethylenediamine. These are chemical compounds with short carbon chains, the ends of which join together in the way shown (bottom right), giving a long chain molecule—nylon.

The two chemicals react together in this way when they are heated in an autoclave (an industrial pressure cooker) in an atmosphere of nitrogen. When a certain consistency is reached, the reaction is stopped. The nylon is cooled and ground to a powder which is stored until required for spinning into a fibre. The actual spinning process is like that described for viscose rayon except that the nylon is not spun from a solution but from a hot melt which solidifies on cooling. After spinning the nylon is drawn to about four times its original length, when it gains its excellent strength and elasticity.



A diagram showing how nylon, a synthetic fibre, is built up by joining together the molecules of adipic acid and hexamethylenediamine.

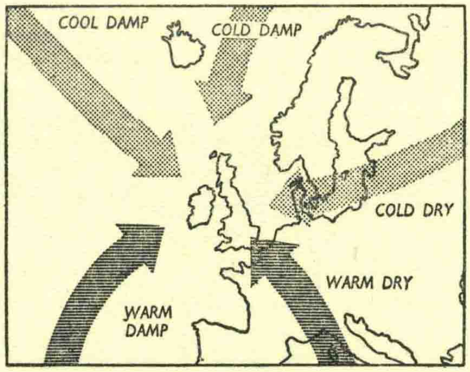
THE STUDY OF METEOROLOGY

Air Masses An air mass is any large body of air which has roughly the same temperature and humidity level throughout (allowing for the fall-off of temperature with height which is fairly constant everywhere). Air masses can develop either where the air is still for long periods of time (such as in the anticyclonic systems of northern Canada, Iceland, Siberia and elsewhere) or where fairly constant winds (such as the south-east trades and westerlies) produce uniform conditions of the atmosphere for long periods of time.

Air masses tend to develop either over the oceans (because temperature and humidity conditions are uniform over huge areas) or over large land masses (where there are no high mountain ranges to bring drastic changes of temperature).

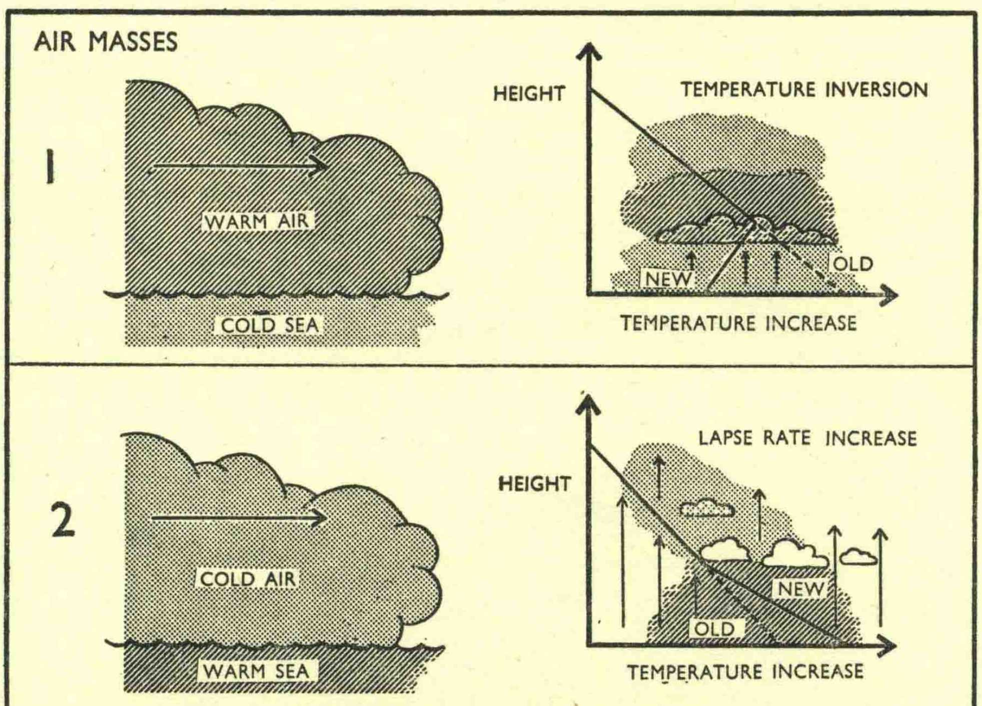
There is a considerable difference between continental air masses (those formed over land) and maritime air masses (those formed over water) because the land is subject to far greater extremes of temperature than the oceans. In winter a continental air mass in high latitudes will be much colder than its maritime counterpart, but in low latitudes much warmer.

Once an air mass has formed definite characteristics, it may move to another area where temperature and humidity conditions are different. The air, always ready to assume the characteristics of the surface over which it is flowing, will then be slightly changed. A warm air mass flowing over a cold surface will gradually be cooled in its lower levels. Then, instead of the air temperature gradually falling-off with height, it will increase for a while (because the cooling process starts from the bottom, leaving the upper air still warm—see diagram 1), producing a *temperature inversion*. This limits convective currents (because warm air will only rise over cold air) and consequently

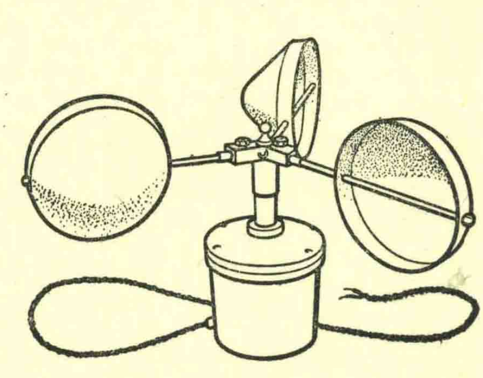


Air Masses affecting the British Isles.

only low stratus "blanket" clouds will form, extending up to the temperature inversion. But since the air is being cooled, it will become more easily saturated (see Dew Point) and clouds will form very easily. This process applies, for instance, to a warm tropical air mass which moves northwards over cold seas to the British Isles, often bringing a steady drizzle. Such an air mass is said to be *stable*. On the other hand, a cold air mass moving over a warmer surface will be warmed in its lower layers. This will increase the *lapse rate* (the rate at which temperatures decrease with height) and encourage the transmission of strong convective currents throughout the air mass with the resulting formation of convective or cumulus clouds (see diagram 2). But since the air mass is being warmed, its capacity for holding water vapour is increasing, a fact which may result in large clouds, heavy rain and thunderstorms later. This process applies, for instance, to polar air moving southwards over warmer seas to the British Isles in summer. Such an air mass is said to be *unstable*.



Anemometer This is an instrument for measuring wind speed. There are many different types of anemometers. The simplest types are based on vanes being turned by the wind and the rotation being communicated to some recording device.



Cup Contact Anemometer.

Anticyclone This is an area of high pressure which may bring calm weather with cloudless skies.

Atmosphere This is a transparent envelope of gas, approximately 500 miles thick, surrounding the earth. It is composed mainly of nitrogen (78%) and oxygen (21%), with very small amounts of many other gases.

The lower levels (up to about twenty miles above the earth) are within the reach of balloons, while lately instrument-packed rockets have gone far beyond the outer limits of the atmosphere. All of these intrusions into the skies have resulted in much valuable information being received on atmospheric conditions.

The first ten miles of the atmosphere are the most important to meteorologists because it is the weather conditions in this layer that directly affect the earth's surface. But as more and more information is being received on the higher levels of the atmosphere it is becoming increasingly clear that they exert a great influence on atmospheric conditions nearer the earth's surface.

Aurora There are many unusual and wonderful sights to be seen in the sky from time to time. They are called weather phenomena. By far the most awe-inspiring of these phenomena is the Aurora Borealis. This is a magnificent display of changing colours in the sky which might take the form of rays, bands, arcs, draperies or diffused lights. Auroras are seen most often in regions near the poles. They are even seen occasionally in northern Scotland. One famous aurora in 1938 could be seen all over England and most of Europe.

The lights of an aurora, which usually occur between 50 and 200 miles above the surface of the earth, are not caused in any way by the reflection of the sun's rays. They provide their own light. It is thought that electrically-charged particles from outer space streaming into the earth's atmosphere are responsible for this strange phenomenon. Auroras often seem to coincide with periods of intense sun-spot activity which may have a bearing on their formation.

Barometer This is an instrument for measuring atmospheric pressure. A barometer reacts to pressure rather like a thermometer reacts to heat. It is composed of a glass tube, sealed at one end, standing upright in a mercury-filled container, with its open end beneath the level of the liquid. Because all the air has previously been drawn out of the tube, normal atmospheric pressure forces the liquid up the tube to a certain height (almost three inches). Any slight variation in pressure will alter the height of the column of mercury. These alterations may be noted from the scale on the side of the tube (which is usually marked in millibars because the variations are so small).

Atmospheric pressure decreases with height above the earth's surface. It also changes frequently at ground level. But it takes very abnormal atmospheric conditions (such as a tornado or an intense anticyclone) to make "the bottom drop out of a barometer" (to drastically lower the pressure reading) or to raise the column of mercury to any great extent.

The Fortin Barometer

Clouds There are four main divisions of clouds: stratus clouds, cumulus clouds, cirrus clouds and nimbus clouds. The height at which they are found and the way in which they combine give definite cloud types as follows:

High Cloud	*Symbol*	*Height*
Cirrus	ci	20–40,000′
Cirro-cumulus	cc	20–25,000′
Cirro-stratus	cs	20–25,000′
Medium Cloud		
Alto-cumulus	ac	10–20,000′
Alto-stratus	as	10–20,000′
Low Cloud		
Stratus	st	0– 5,000′
Nimbo-stratus	ns	3–10,000′
Strato-cumulus	sc	3–18,000′
Cumulus	cu	3–10,000′
Cumulo-nimbus	cni	3–40,000′

Layer or "blanket" clouds are produced by a front or other temperature inversion (see Air Masses). They include all types of stratus clouds. When layer clouds begin to break up through turbulence in the atmosphere, high and medium cumulus clouds may be found including cc, ac, and sc. Cumulus (cu) and cirrus (ci) clouds are formed by strong convection currents when an air mass is unstable (see Air Masses). Cumulo-nimbus, the great thunder cloud, is a development of the cumulus (cu) type.

Top—Cirrus: Middle—Stratus: Bottom—Cumulus.

Cold Front This is an imaginary line dividing a warm air mass from a following cold air mass.

Condensation is the changing back of water vapour to the liquid state. The water droplets produced may, in time, form clouds or fog or, at very low temperatures, ice crystals. When an air mass is in contact with a water or land surface, condensation begins as soon as the temperature falls below *dew point* (see below). If the small water droplets produced continue to grow, they will become too heavy to float in the cloud and will fall as rain. But since a raindrop is one million times larger than a cloud droplet, precipitation (rainfall) is really a separate process.

There are many little particles floating in the air upon which the water vapour is able to condense. These particles are called *condensation nuclei*. They include such things as salt, evaporated from sea spray, and smuts from smoke. There are obviously far more impurities in the air over an industrial town than over the open countryside but fortunately it is the size of the particles rather than their number which determines whether or not condensation will take place upon them.

When condensation first begins, water droplets only gather on the larger particles. But as it continues, the smaller condensation nuclei become *active* also.

Until a *relative humidity* (see page 175) of 100% is reached there is a tendency for the water droplets to evaporate. Beyond this level, however, they grow very rapidly. The point where the droplets are just about to greatly increase in size is called the *critical supersaturation level*. It becomes progressively higher the smaller the condensation nuclei.

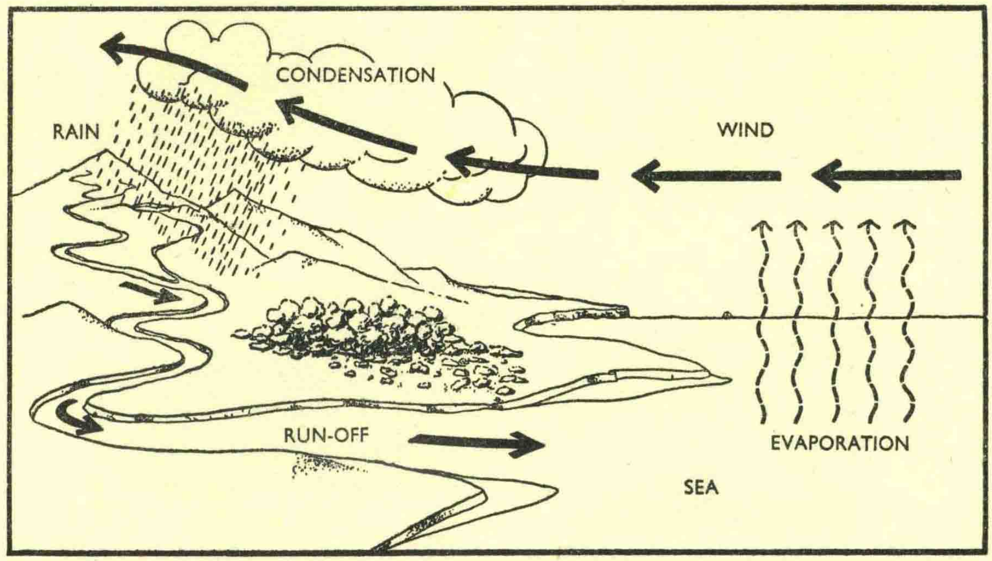
Convection This is the rising of warm air because it is lighter than cold "dense" air. Convection plays an important part in rainfall (see page 175).

Cyclone (Depression) This is an area of low pressure which may bring disturbed weather, rainbelts and high winds. A tropical *typhoon* or *tornado* is simply an area of very intense low pressure.

Dew Point Warm air can hold more water vapour than cold air. If a mass of warm, moist air were slowly cooled, it would start to deposit its excess water vapour in the form of dew or cloud droplets at a certain temperature. This temperature is called the dew point.

Evaporation In meteorology this entails the conversion of water to vapour by heat. A warm air mass passing over an ocean evaporates water from the surface. The amount evaporated depends upon the length of time the two are in contact, the temperature of the air and the amount of water vapour it already contains. Under similar conditions, warm air can hold far more water vapour than cold air without becoming *saturated*.

The Cycle of Evaporation and Rain.



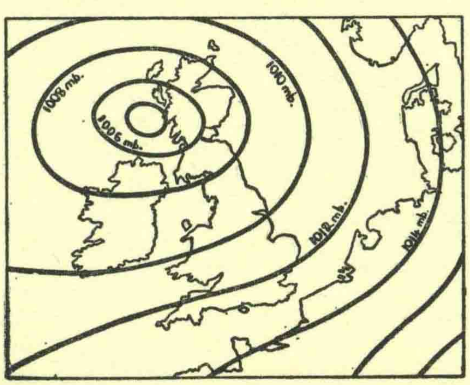
Fog This is simply a type of stratus cloud (see Clouds) forming near the ground. Fog is said to be present when the visibility is less than 1,100 yards. There are many different kinds of fogs. *Radiation fog* is produced when the ground cools at night and chills the air lying immediately above it, causing condensation. It is usually quickly dispersed in the morning either by sunshine or wind. *Advection fog* is produced by a warm air mass flowing over a cold surface. Warm air blowing out from the Californian valley, for instance, meets the cold Californian current, sweeping down from the Arctic, and causes constant off-shore fogs. *Arctic smoke* is formed by cold air passing over a warm sea and mixing with the air lying above. *Smoke fogs* occur mainly in industrial centres. They are due to the large amount of dust particles in the air (especially when warm air lying above cold air stops the smoke from rising above a certain height). When smoke fog is combined with ordinary water vapour fog, the worst possible type of fog is produced—*smog*.

Frost This is formed by the condensation of water vapour on surfaces with a temperature below freezing point. Frost describes the beautiful fern-like patterns of ice crystals which may form on window panes during very cold weather. They are caused by warm, moist air inside the house coming into contact with the cold glass. The term also includes *hoar frost*, which often makes the ground sparkle on a cold winter's morning. *Rime* consists of frozen fog particles.

Frost Patterns

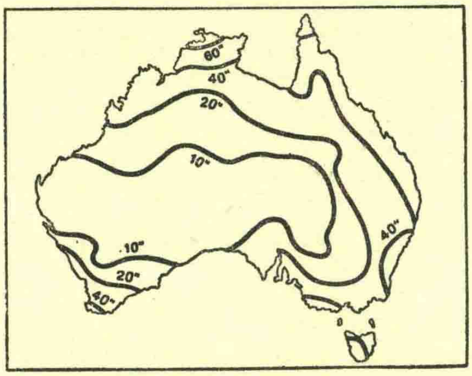
Humidity. The humidity of air is the amount of water vapour it holds. The actual amount may best be expressed as a percentage of the water vapour that the air mass could hold at that temperature without condensation taking place. This percentage is called the *relative humidity*.

Isobars are lines joining points of equal barometric pressure on a weather map. Just as contours show high and low areas of land on a ground relief map, isobars show high and low pressure areas (anticyclones and depressions).



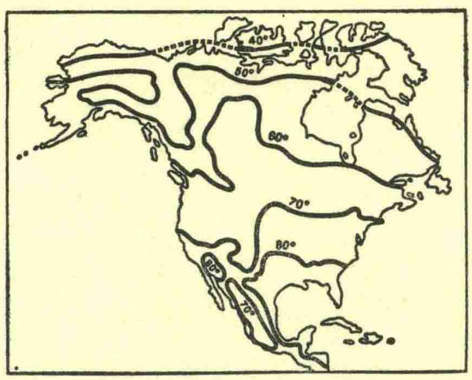
Isobar (Pressure) Map

Isohyets are lines joining points of equal rainfall on a map of rainfall regimes. Usually those areas bounded by similar isohyets are coloured similarly.



Isohyet (Rainfall) Map

Isotherms are lines joining points of equal temperature on a map of temperature zones. They show particularly how certain physical factors, such as ocean currents and mountain masses, can affect temperatures.



Isotherm (Temperature) Map

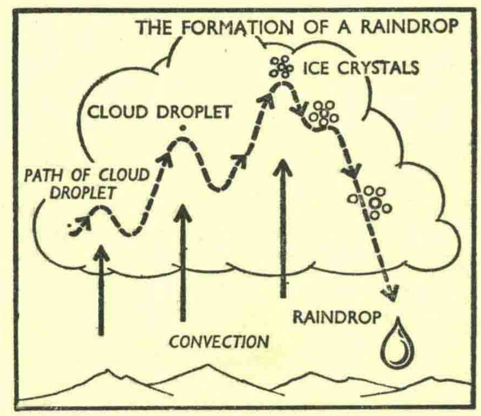
Monsoon This is an interruption of the normal planetary wind pattern. It is based upon the fact that winds flow from high to low pressures. In winter a very high pressure area builds up over the great, cold land mass of Asia, causing winds to flow outwards towards the equatorial low pressure regions. But in summer, conditions are entirely reversed; an intense low pressure area develops over the heart of Asia due to the heat built up by the great mass of land. Moisture-laden winds now rush in over the land from the Pacific Ocean, bringing torrential rain. The subcontinent of India has its own monsoon, and other great land masses have monsoonal tendencies.

Occlusion A mass of warm air completely cut off from the ground by dense, heavy, cold air is said to be occluded.

Precipitation—See Rain.

Rain This is the end product of condensation (see page 174). As cloud droplets increase in size they tend to fall to the ground. But at this stage they are so small that ascending air currents may carry them aloft again. Even if they do begin to fall they might be evaporated by warm air at lower levels. A cloud droplet's only chance of survival is to collide with other droplets and so increase its size that neither air currents nor evaporation can stop it falling to the ground as a raindrop.

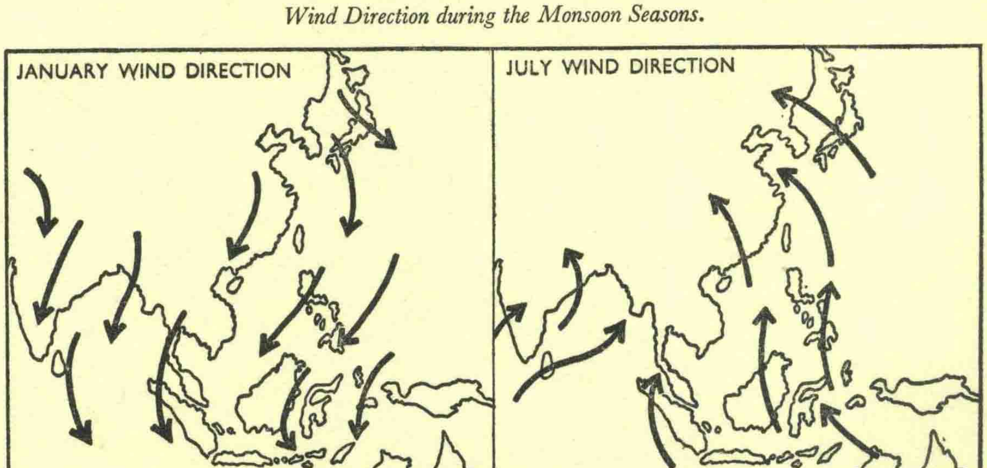
The heaviest rain is produced by cumulus clouds (see Clouds) where strong air movements give the water droplets more chance of colliding. In stratus clouds (see Clouds), on the other hand, weak air currents limit the size of raindrops.



Another method of rainfall, the Bergeron or cold rain process, takes place when the air temperature is below freezing point. In this case ice particles mainly take the place of water droplets. As they grow in size and fall through the cloud water vapour freezes on to them (a process called *sublimation*). When passing through warmer air near the ground, the ice crystals may change to snowflakes or even to rain.

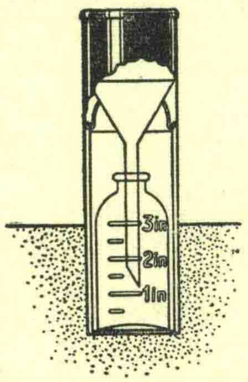
Rainbow As its name implies, this beautiful colour effect in the sky is closely associated with rain. In fact it can only be seen during

Wind Direction during the Monsoon Seasons.



a shower when the sun is shining. A rainbow is caused by the refraction and reflection of the sun's rays by the water droplets, each one of which acts as a mirror.

Rain Gauge This is one of the simpler meteorological measuring instruments. Basically, it consists of a metal collecting tube leading down into a graduated glass container from which a reading can be obtained of the amount of rainfall received over a given period.



Snowdon Rain Gauge. Melted snow from the collecting funnel drips into the glass jar.

Relative Humidity See Humidity.

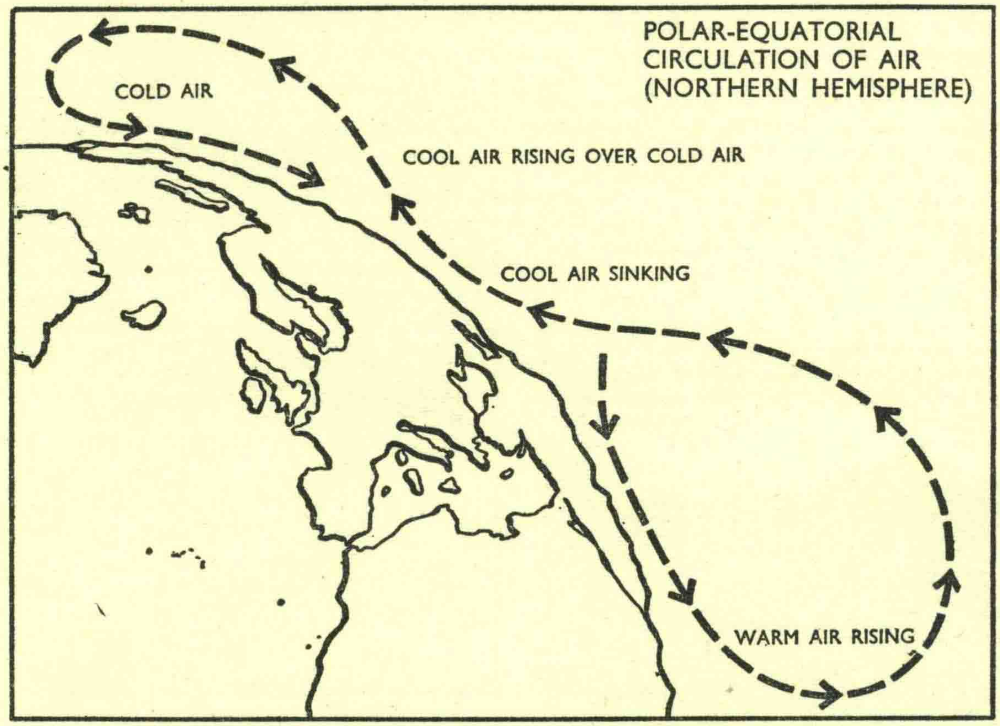
Snow See Rain.

Supersaturation When an air mass is in contact with the ground or water, condensation (see page 174) begins as soon as the temperature falls below dew point (see page 174). If, however, the air mass is not in contact with a land or water surface, the relative humidity (see Humidity) may reach 500% before condensation takes place because there will be few solid particles such as sea salt for the water vapour to condense upon. The air is then said to be *supersaturated.*

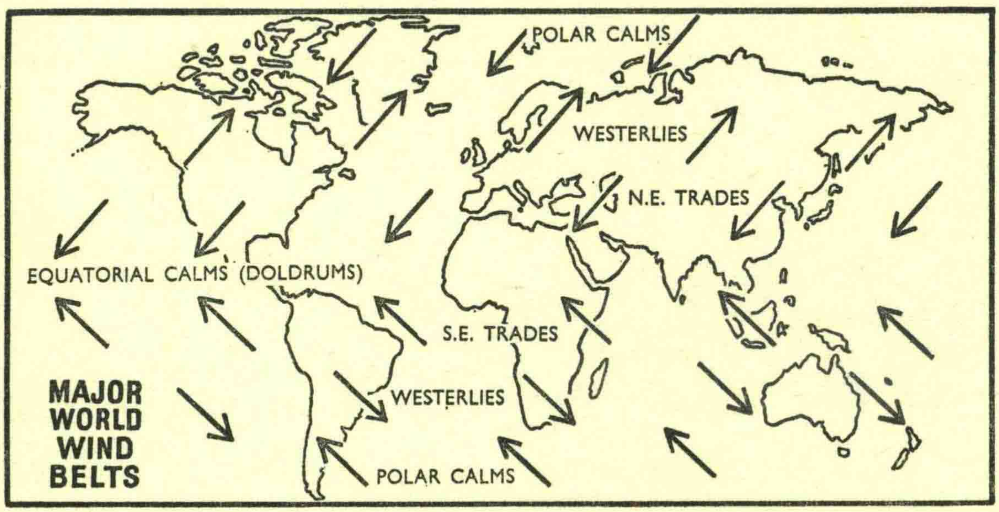
Warm Front This is an imaginary line dividing a cold air mass from a following warm air mass.

Weather This is the day-to-day conditions of the atmosphere at a certain place. It should not be confused with the term "climate", which describes the average type of weather usually received over a large area during the course of the year. In some places "weather" is almost "climate"—i.e. it changes very little throughout the year. In other places, however, it can change completely within the space of a few hours. It is not unknown for rain to fall on one side of a street but not on the other! The British Isles usually has very changeable weather. This is due to anticyclones (high pressure) and depressions (low pressure) following one another in from the Atlantic, bringing changing atmospheric conditions in their wake. Even the British weather, however, tends to have its habits. If it is sunny for two days, for instance, the following day is more likely to be fine than rainy. This is because the weather of Western Europe largely depends upon the dominant pressure system (see Air Masses). These major pressure systems weaken very gradually, hence the tendency of weather to stay the same for a period of time.

Wind This is simply the movement of air which results from the uneven heating of different parts of the earth's surface by the sun. There is, broadly speaking, a general transference of air between low and high latitudes. Air at the equator receives much heat from the sun. The warm air rises and moves towards the poles, cooling as it goes, and consequently sinking to the ground in high latitudes. Then it is drawn towards the equator to fill the space (low pressure area) left by more air rising. Both the simple planetary circulation of air and the way in which the spin of the earth, by deflecting the winds, alters this pattern are pictured on page 178.



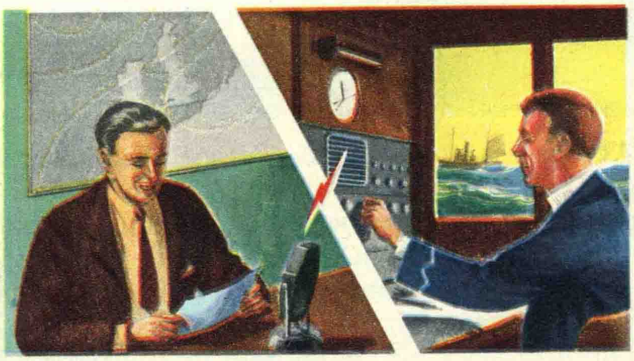
Even this is not the whole picture as far as the surface wind pattern of the world is concerned. For the simple planetary circulation of air actually takes place in two phases. Warm equatorial air, travelling northwards, gradually cools and sinks to the ground in middle latitudes. Part of it turns back towards the constant low pressure region centred on the equator (forming the north-east trade winds) while the rest continues on but at ground level (forming the westerlies). Finally, the now cool, northward-bound air meets cold air travelling from the polar high pressure area, and rises over it. This process takes place in the southern hemisphere too. All of the winds would blow either northwards or southwards if they were not deflected by the spin of the earth to form the pattern shown in the diagram. The trade wind belts do move slightly with the changing seasons—northwards in winter and southwards in summer. Many factors can upset the planetary wind circulation, particularly the development of high or low pressure areas over the great land masses, and relief. The monsoon of Asia is a good example of how the surface wind pattern can be entirely upset. Smaller pressure systems, such as the Atlantic anticyclones and depressions, are constantly causing local wind variations.



WEATHER FORECASTING

In some areas of the world, particularly equatorial and polar regions, the day to day weather follows such a regular pattern that it is possible to make a fairly accurate forecast months or even years ahead. On the other hand, there are many areas, such as Western Europe, where it is sometimes difficult to predict weather conditions even one day ahead.

To prepare an accurate weather forecast, say 24 hours ahead, a meteorologist would need detailed and frequent reports of atmospheric conditions, both at ground level and in the upper air from a large surrounding area. These are supplied by meteorological stations, airfields and weather-ships. To an ordinary person weather forecasts are simply a benefit but to shipping and aircraft they are invaluable.



Few people have not heard the words " Here is a gale warning " interrupt normal radio programmes at some time or another. Such warnings are intended for the benefit of shipping. Normal weather reports and forecasts for shipping are broadcast twice daily.

U.S. naval planes are sometimes engaged upon the difficult task of finding a hurricane and plotting its path. The reports they send in give people ample warning of a storm's approach.

TO RECORD ATMOSPHERIC CONDITIONS IN THE UPPER AIR AN AUTOMATIC RECORDING AND RADIO TRANSMITTING EQUIPMENT (CALLED RADIOSONDE) IS BORNE ALOFT BY A GAS-FILLED BALLOON. WHEN THE BALLOON BURSTS THROUGH EXPANSION (SEE PAGE 98) THE EQUIPMENT IS PARACHUTED SAFELY BACK TO EARTH.

Left. Simple circulation of air to poles. *Right.* Actual circulation complicated by earth's rotation. See Glossary, WINDS.

THE STUDY OF WEATHER

Orthographic rain (usually reliable and often heavy) is caused when warm, moist air is forced to rise to colder levels by mountains lying in its path.

Cyclonic rain (often a steady drizzle) is caused by a wedge of cold air lifting a mass of warm, moist air until rapid condensation takes place.

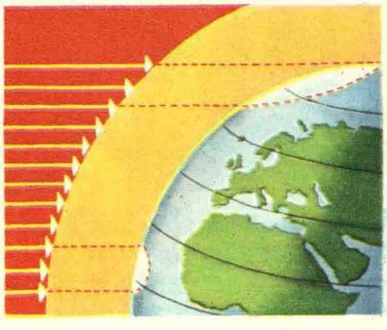
Convectional rain (light or heavy showers) is caused when moist air, warmed by contact with the ground, rises and rapidly cools.

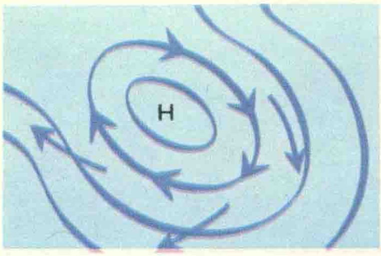
Weather is the day to day conditions of the atmosphere in a certain place with regard to temperature, barometric pressure, wind, humidity and rainfall. Climate is the weather of a certain area taken over a long period of time. It is the average of many small variations.

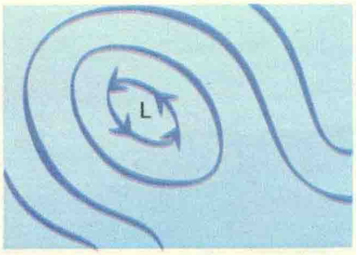
The primary cause of climate in any part of the world is the share of the sun's heat it receives. This depends upon latitude (see illustration below) and generally, the further from the equator, the cooler the climate.

Rainfall distinguishes the type of climate. The amount of rainfall is governed by many factors, but in particular, the relative position of land and sea, and the wind direction (see page 179).

Areas in high latitudes receive less heat from the sun than those in low latitudes. This is mainly due to the curve of the earth. Near the poles, the sun's rays strike at an oblique angle, causing the same amount of heat as received at the equator to be spread over a greater area.



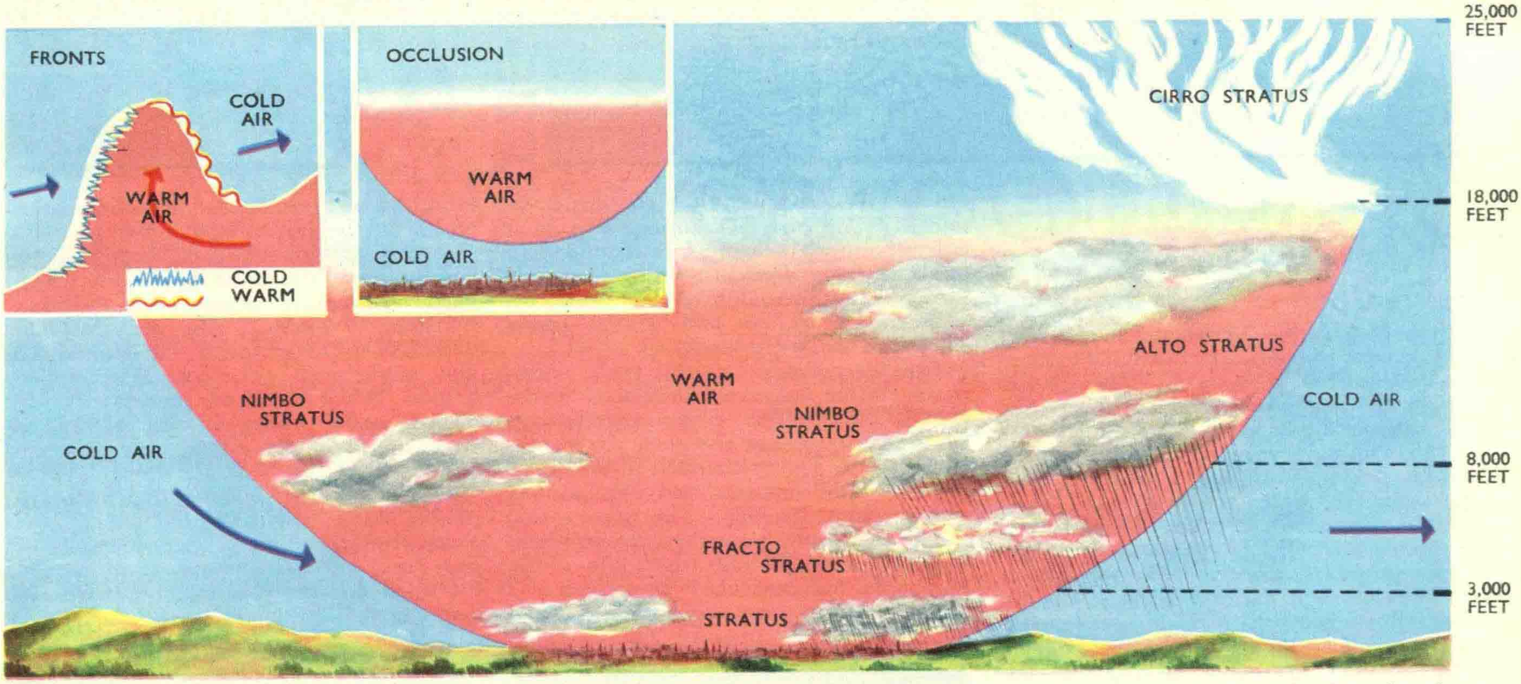




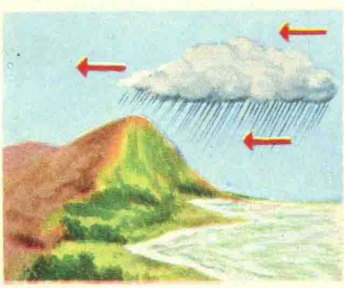
When air is warmed it rises, leaving behind an area of low pressure. Cold air, on the other hand, is dense and tends to sink, causing an area of high pressure. Winds flow from high to low pressure areas just like water flows downhill. Cold air (high pressure) surrounded by warm air (low pressure) forms an anticyclone; reversed positions form a cyclone. In the northern hemisphere, outward blowing winds from an anticyclone (high pressure area) are deflected by the rotation of the earth in a clockwise manner and inward blowing winds to a cyclone (low pressure area) in an anticlockwise manner. In the southern hemisphere, the reverse is true. Isobars are lines joining points of equal pressure. Like contours on a map which show high and low land, they show high and low pressure areas on a meteorological map.

Many local features greatly complicate climate. The sea does not heat up as quickly as the land but keeps its heat longer. Therefore it brings a cooling influence in summer and a warming influence in winter to the temperatures of coastal areas. On the other hand, those areas far from the sea suffer from very hot summers and very cold winters. Temperatures are also lower the greater the height above sea level. The most striking example of this fact is the snow capped peak of Mt. Kilimanjaro which lies in East Africa on the equator.

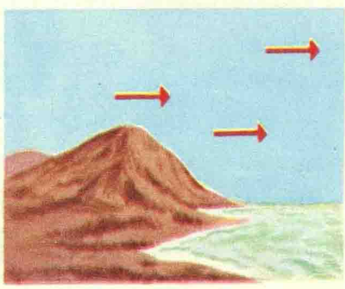
Weather in tropical and polar regions follows a fairly definite pattern. But in middle latitude areas constantly changing atmospheric conditions make accurate forecasting very difficult.



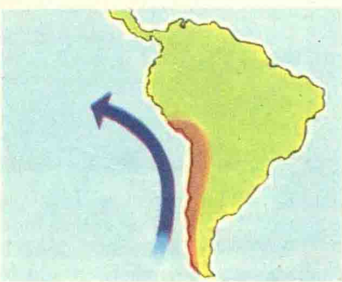
When a warm air mass follows a cold air mass, the imaginary line dividing the two is called a *warm front*. The reverse position produces a *cold front*. As the warm air tends to rise over the " ramp " of cold air in front, it cools, and condensation takes place, producing clouds and rain. An *occlusion* is where the following cold air mass acts as a wedge, lifting the warm air and cutting it off from the ground completely.



On-shore winds are able to shed the moisture they have picked up from the sea on coastal ranges.

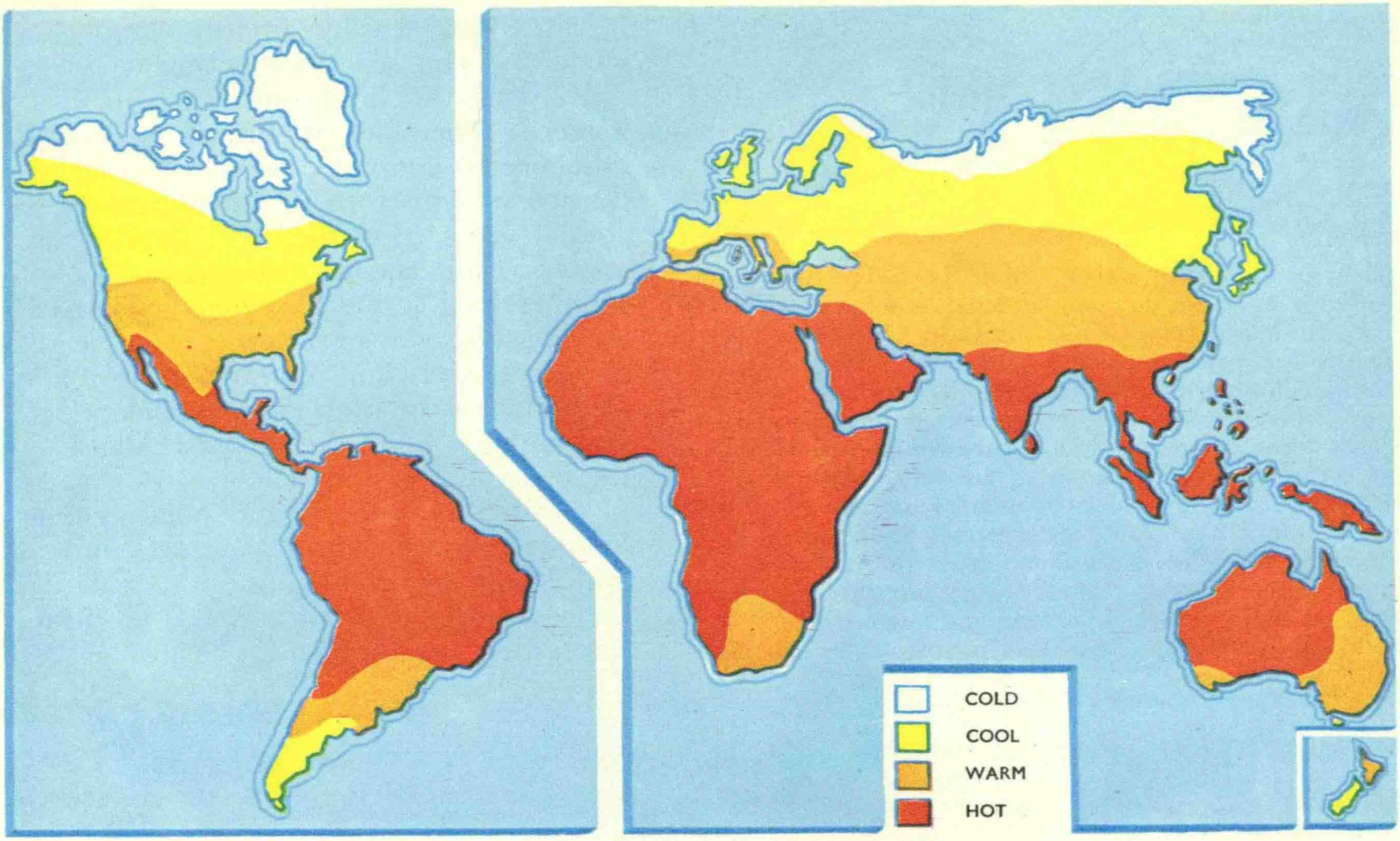


Off-shore winds are dry, having travelled over land. They can bring little rain to coastal areas.



Cold coastal currents can cause deserts, for passing winds are chilled and unable to pick up moisture.

Height affects temperatures. Here, cool mountain scrublands overlook hot, damp, coastal forests.



Climates

HOT CLIMATES are found in areas near the equator where the mean annual temperature never falls below 70° F. The Amazon Basin, the Congo Basin and the East Indies, all straddle the Equator. The rainfall here is heavy all the year round and temperatures seldom drop beneath 80° F. The air is very sticky which makes the heat even worse. Dense gloomy forests cover the land.

Either side of this equatorial zone the temperature falls slightly. Now, the amount of rain received varies a great deal, and natural vegetation, which corresponds to rainfall, ranges from the tropical "Savannah" grasslands of Africa to the dense forests of Central America. India, South-East Asia and North-East Australia have an unusual type of rainfall called the monsoon. It is due to intense low pressure areas developing over the land. Winds rush into these low pressure areas bringing torrential rain.

The great hot deserts, including the Sahara of Africa and the interior of Australia, lie in the trade wind belts (see page 8) where winds flowing towards the equator are warmed and tend to absorb moisture rather than shed it. Temperatures are high all the year round but fall rapidly at night. The rainfall might be less than one inch per year.

North and south of the hot climates lie the WARM CLIMATES, where the mean annual temperature never falls below 43° F. On the eastern side of the continents, summers are hot and wet, winters cool and dry. The natural vegetation is a type of evergreen forest, and the rainfall is high. On the Western side of the continents the rainfall is less and falls during the winter. (Mediterranean climate). The natural vegetation includes drought-resisting trees and shrubs. In the middle of the continents summers are warmer and winters cooler These are the steppelands.

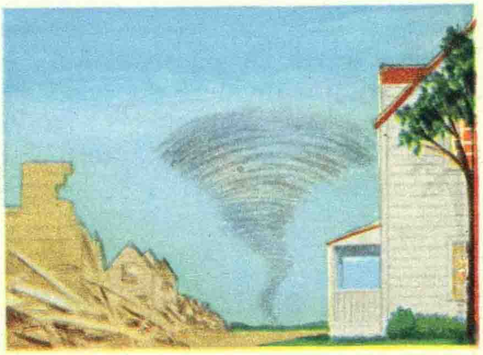
The warm climates quickly grade northwards (in the northern hemisphere) to the COOL CLIMATES where temperatures fall below 43° F. for less than six months of the year. The eastern side of the continents has hot summers and cold winters with moderate rainfall. The western side of the continents has mild winters, warm summers and ample rain which falls all the year round but particularly in autumn and winter. The natural vegetation includes meadows and woodlands. This climate is typical of the British Isles.

In the north of Asia and North America lies the great coniferous forest belt which northwards again grades into the cold "Tundra" wastes. In such COLD CLIMATES snow covers the ground for most of the year. The natural vegetation is moss, lichen and small bushes.

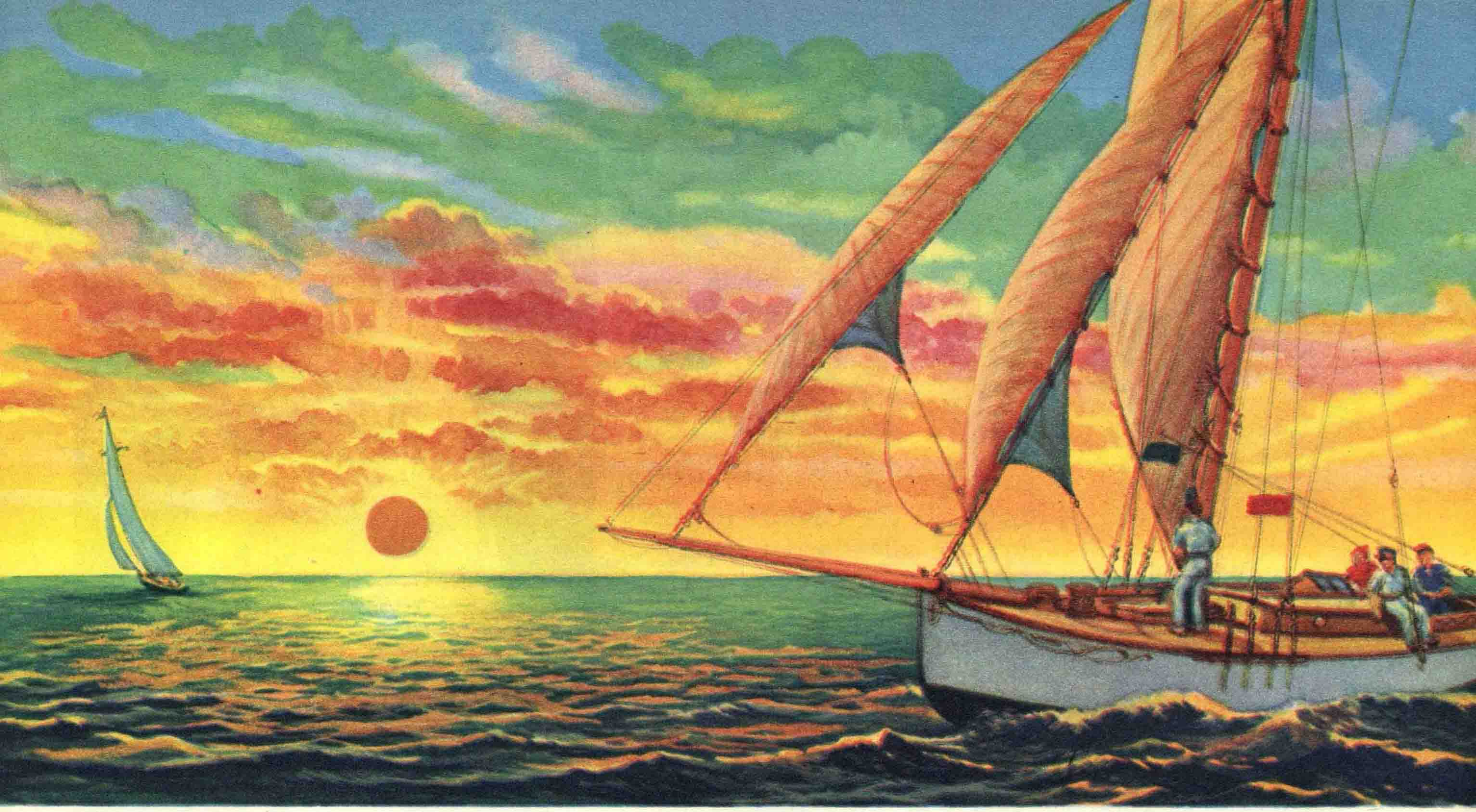
The snowy wastes of the interior of Greenland, and Antarctica, have no vegetation whatsoever.

It must be borne in mind that in mountainous areas, height greatly modifies the general temperatures of the region. But such areas with *mountain climates* are usually too small and complex to be shown on a world map.

The towering, black, anvil-shaped Cumulo Nimbus, or storm cloud, grows from fluffy white Cumulus cloud heaps. The tremendous growth is caused by rapid condensation through warm air rising very quickly. Lightning is static electricity leaping from cloud to cloud, or to the ground. Thunder is the noise of air, greatly heated by lightning, expanding rapidly.



A tornado is a tube of intense low pressure around which winds whirl at speeds often over 200 miles per hour. Fortunately, the whole storm moves fairly slowly across the countryside, giving people ample warning of its approach. Tornadoes in the American Mid-West have been known to carve a narrow path of destruction through villages leaving buildings on either side unharmed.



There are few more colourful scenes in nature than those at the end of the day when the sun sinks slowly in the West, casting rays of red and yellow light over much of the sky. The reason for this amazing phenomenon is explained below.

THE LAWS OF COLOUR

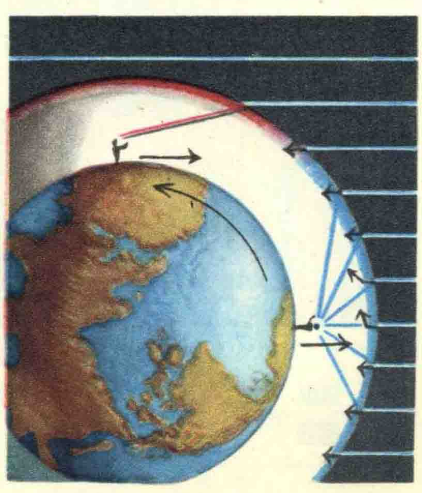
One of man's greatest assets is his ability to see and distinguish colours. They give great pleasure, as well as performing a useful function in nature. Many animals, however, are unable to distinguish colours, and see the world in terms of black and grey.

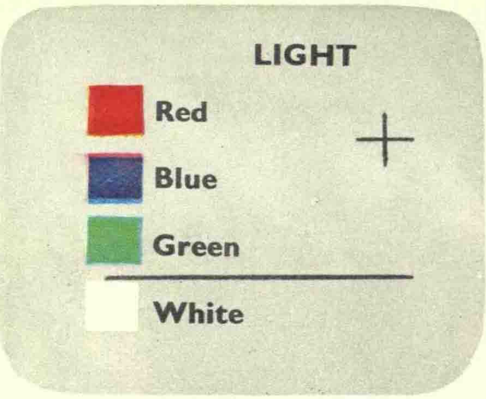
What we see as white light is in fact made up of all the colours in the rainbow. This can easily be demonstrated by passing white light through a prism so that it is refracted. As the diagram below shows, it is split up into colours. This range of colour is known as the *spectrum*. It extends from violet at one end to red at the other. As it passes through the prism, each colour is bent at a different angle. Red has the least deviation, violet the greatest.

In order, the colours of the spectrum are red, orange, yellow, green, blue, indigo and violet. Outside the visible spectrum are other rays. Though our eyes cannot distinguish them as colours they can be readily detected. The infra-red rays have a marked heating effect and the ultra-violet rays affect a photographic film.

The diagram shows how white light (from a source on the left) is split into its separate colours when passed through a prism. Passed through another it can be returned to its original form. In practice the bands of colour will not be so well defined.

At mid-day an observer sees mainly the blue rays, dispersed about the sky. At sunset, the earth has turned, and the man will now see mainly the red and yellow rays. Dust and gases in the atmosphere have deflected the blue rays, leaving the red to pass on unaffected.

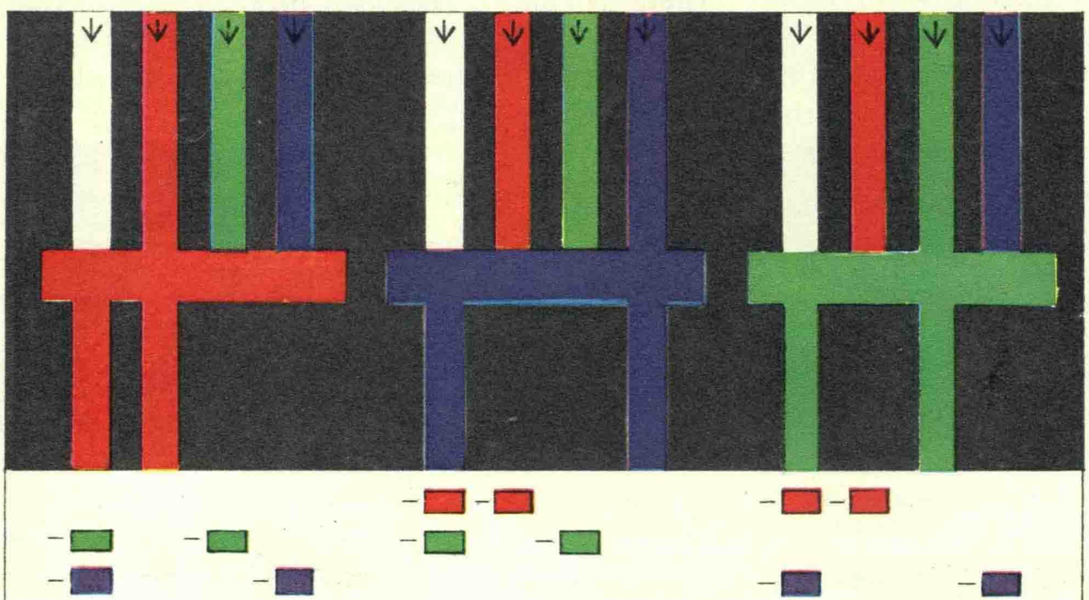




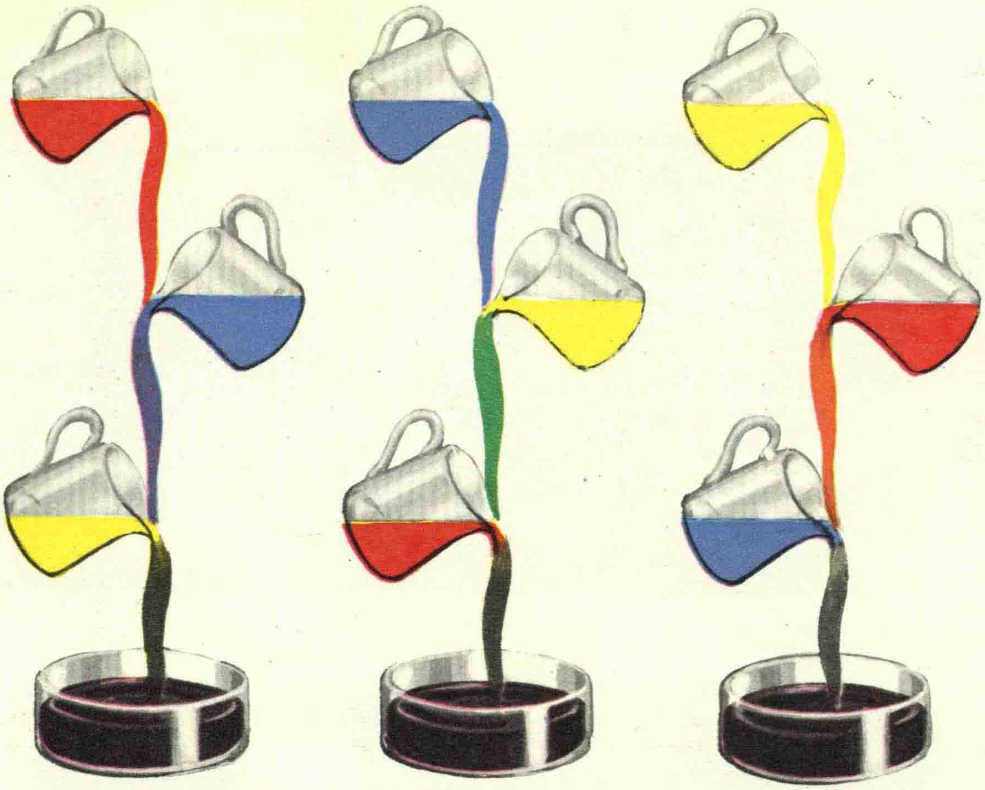
ADDITION. The singer spotlighted in red, green, and blue light appears as though she is in a white light. Blue light added to green light make turquoise, red and green make yellow, red and blue make magenta.

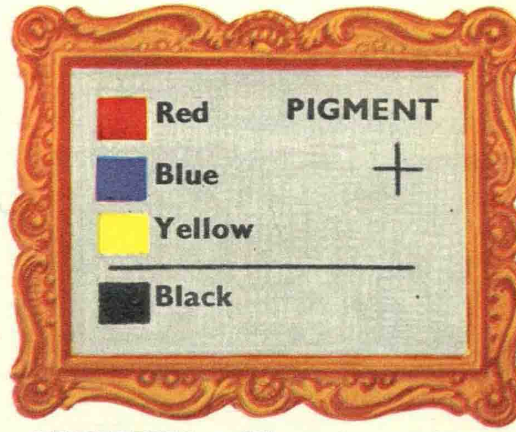
White light is made up of all the colours in the spectrum. If those colours are all added together, white light is produced. In practice, however, a near approximation to white can be made by adding together green, red, and blue. If these colours are blended in varying proportions, varying hues can be obtained. The stage-lighting expert can produce the colours he needs from floodlights which are red, green and blue. When he turns out the blue, the stage becomes yellow. When he puts on the blue and green, but omits the red, he produces turquoise. The crooner in the spotlight can be shown white by training a red spot on her while the floodlights show blue and green. If some of the coloured lights are brighter than the others, varying shades can be produced. In this case a too powerful red spot will produce a pinkish shade on the singer's face.

As in light colours can be added together, so they can be subtracted. The use of filters enables us to cut out some of the colours, leaving the rest to travel on. A photographer may use a red filter to cut down or remove completely the blue and green colours, a green filter to remove red and blue, and a blue filter to take out the red and green. A pale filter is less effective in removing the other hues than a deep one, but is often more useful to a photographer, since to remove one colour entirely from a colour snap-shot would completely destroy the appearance of reality.



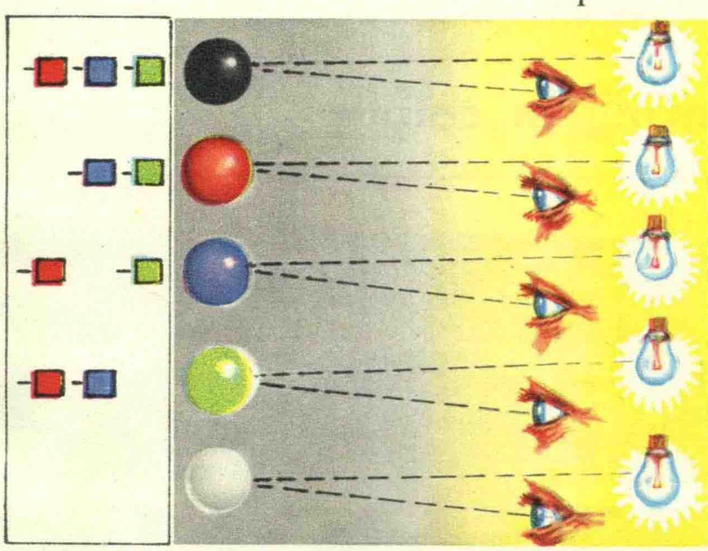
SUBTRACTION. Filters can be used to eliminate colours in light. White light passed through a red filter loses the blue and green to become red. Passed through a blue filter it becomes blue, losing the red and green. A green filter takes out the blue and red, allowing only the green to pass. When a primary colour of a hue different from that of the filter itself is passed through, the result is black or complete absence of light. In practice it is difficult to obtain absolute true colour filters.





ADDITION. The three basic pigment colours, red, blue, and yellow, when added together produce black. Red and blue added make purple, blue and yellow make green, and yellow and red make orange. Since the effect of any pigment is to take away something from white light (subtraction), we can get white only if we use no pigment.

When we look at an oil painting or at any coloured surface, our eyes receive rays which have been *reflected* from the object. What happens is that they absorb some of the hues, and reflect the others. In our colour arithmetic we are subtracting. A surface which reflects practically all the sunlight reaching it appears to us as white. One which absorbs all colours and reflects none appears black. The substances which are used in paints to reflect the various colours are known as pigments. The diagram (lower left) shows how red, blue, and green, absorb and reflect light.



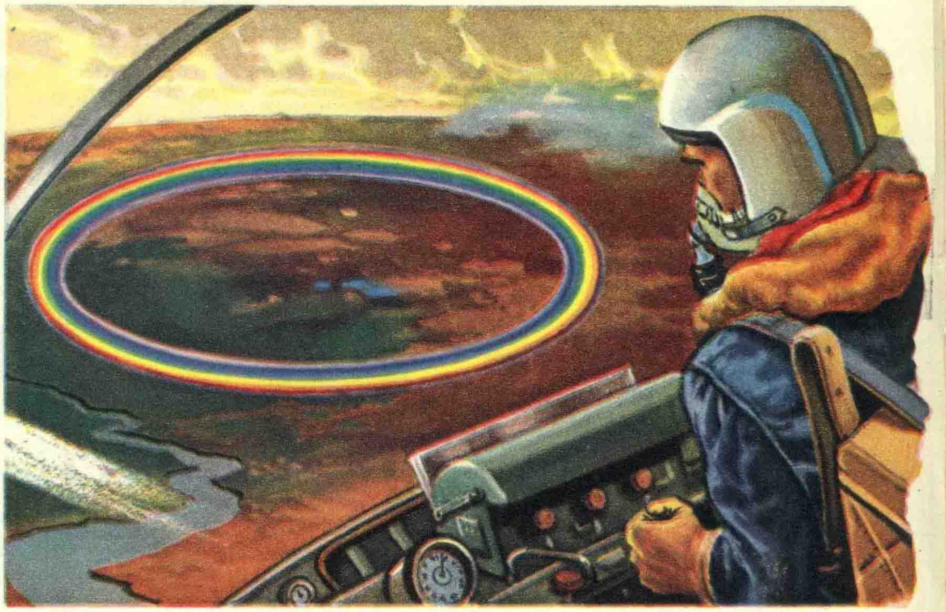
SUBTRACTION. The diagram shows how the coloured surfaces absorb part of the light directed at them, and reflect the rest. A black surface absorbs all the colours, and no light is reflected. Red pigment absorbs blue and green light, reflecting red. Blue absorbs red and green light, reflecting blue, and green absorbs red and blue, reflecting green light. A white surface reflects all light and none is absorbed.

In the mixing of colours with pigment, it is not possible to produce white from a combination of the other colours. This is because each component colour (red, blue and yellow) in a mixture of all three absorbs so much of the others from the light that the total result is black, an absence of all reflected colour. It is, however, possible to produce practically every colour by mixing the three primary pigments in varying proportions, just as in addition of light. In order to do this satisfactorily, the *tone* pigment primaries must be used, namely greenish-blue (cyan), bluish-red (magenta), and yellow.

One of the difficulties faced by manufacturers of paints and other coloured products is the problem of describing colours, in order to match them. Of the various methods, one of the most successful is to classify colours according to three qualities. These are hue, intensity, and tone. What is meant by hue is the amount of each primary colour present in a mixture. Intensity refers to the 'brightness' of a colour (e.g. bright red, dull grey). Tone refers to the darkness or lightness of the colours. In this way all colours can be described with a reasonable degree of accuracy.

The Uses of Colour

It would be a drab world without colour. Many of the colours in nature, however, have been evolved for special reasons. Highly decorative flowers, for example, attract bees and other insects to help in pollination. The dramatic hues of the peacock give it added attraction for its mate. Man, too, is very responsive to variety in colour. Industrial psychologists have found that machinery and factory walls painted in certain colours give a boost to morale and increase production. Drab-coloured surroundings have a most depressing effect and can affect health and efficiency.



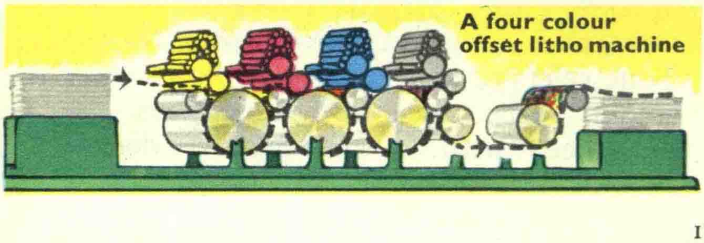
A rainbow is produced by light from the sun behind the observer being refracted by raindrops, each of which splits the white light into its component colours in the same way in which a prism produces a spectrum. Though normally it is possible to see only a part of the rainbow from ground level, a pilot in a plane high in the air may see the complete circle.

The use of this yellow filter makes it appear that the cowboy scene is taking place by moonlight. Filters are much used in colour photography.

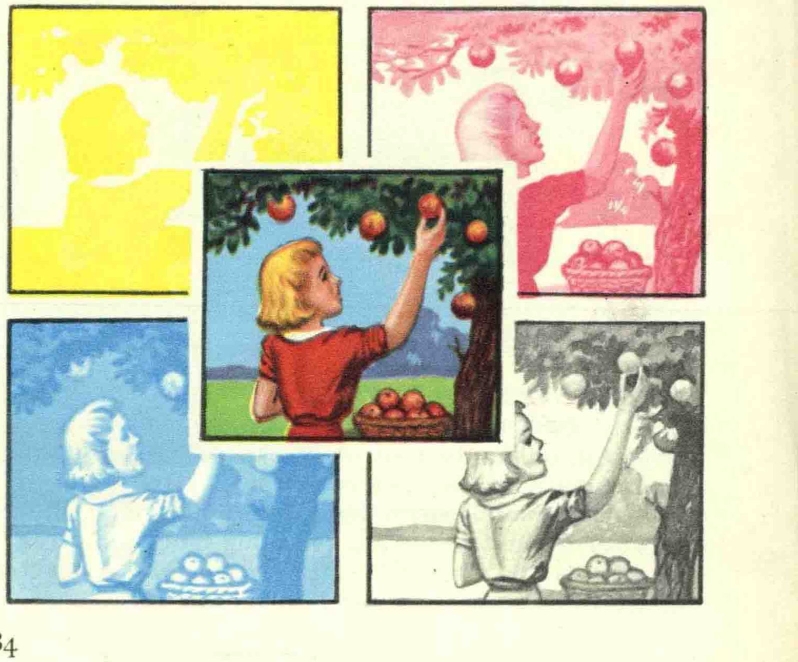
Scientists have found that the light from stars is made up of colours in unusual proportions. When analysed through a spectroscope (basically a prism) the rays from some stars contain a distinct band of yellow light. It is known that the glowing sodium also has this characteristic, and therefore these stars are shown to be partly made up of that element. Many, if not all elements can be traced in this way, and it is thus possible for astronomers to work out the composition of stars with a considerable degree of accuracy, purely by examining the colours in the light they give out. These studies have even led to the discovery of an element in the sun—helium, previously unknown on earth.

Printing in colour

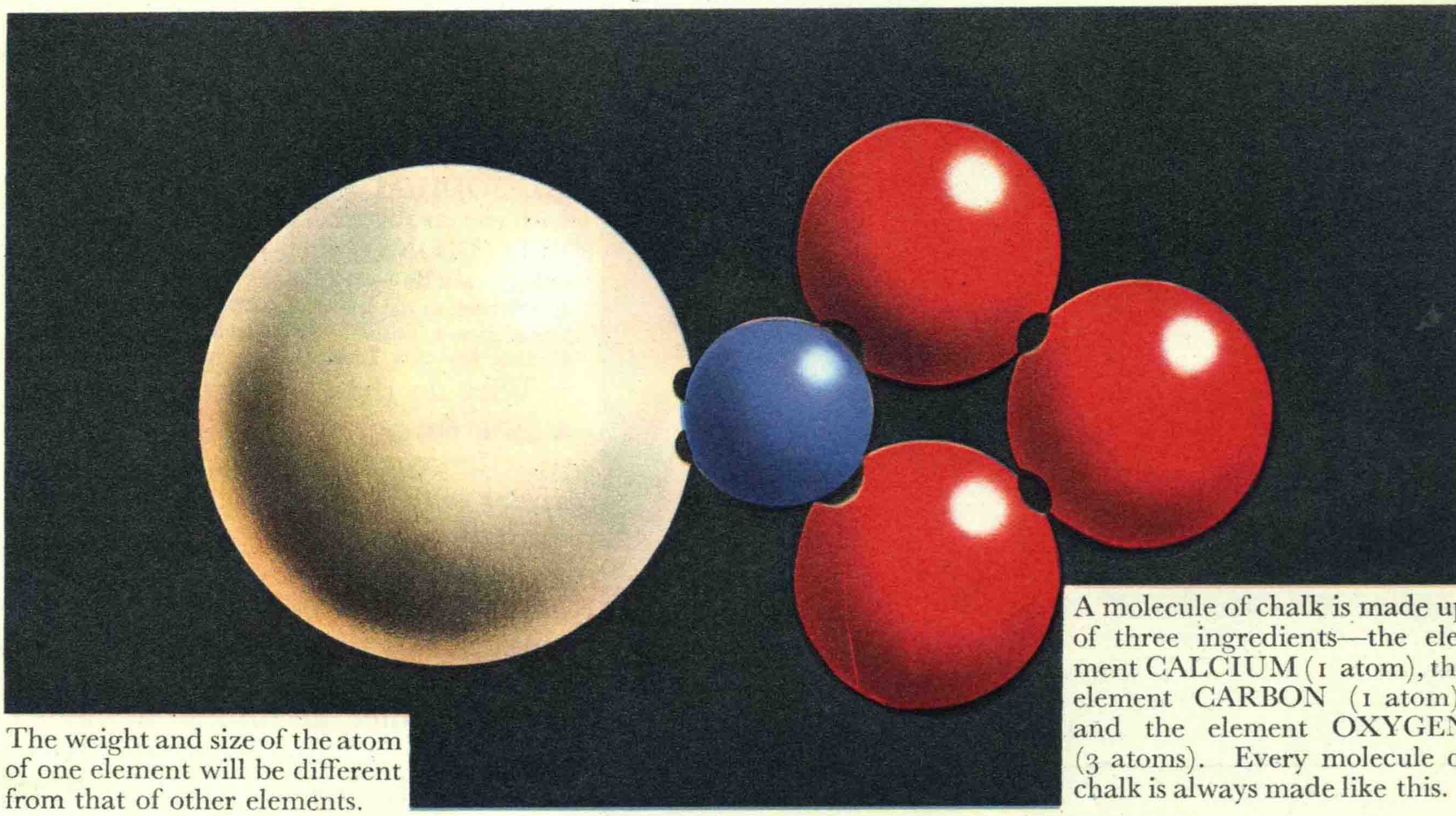
The pictures on this page are made up of thousands of tiny dots of red, yellow, blue, and black ink. Together they give the impression that all colours and shades are present, because the eye is deceived into considering them as flat colours. The larger the dots of one colour, the stronger it will appear. Thus purple will have large blue and red dots and much smaller yellow and black dots. Because one opaque printing ink would hide another below it, printers prepare their plates to ensure that each group of dots falls clear of other groups.



A four colour offset litho machine



THE SCIENCE OF CHEMISTRY



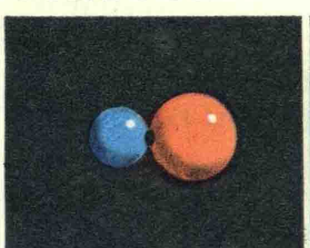
The weight and size of the atom of one element will be different from that of other elements.

A molecule of chalk is made up of three ingredients—the element CALCIUM (1 atom), the element CARBON (1 atom), and the element OXYGEN (3 atoms). Every molecule of chalk is always made like this.

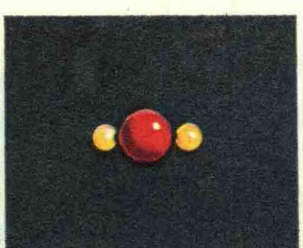
The materials which make up our world are very numerous, many of them similar in appearance, though quite different in behaviour.

After hundreds of years of puzzling research the explanation is now known. There are in fact about a hundred basic ingredients (in nature) called ELEMENTS. From these all other materials are made. A substance made up of more than one element is called a COMPOUND.

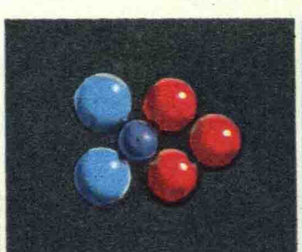
The smallest part of an element or compound that can exist in a free state is a MOLECULE. This means that the properties of a substance depend on the parts it is made up of remaining intact. If the molecules are split or added to, the substance will then have different properties, since the individual parts that make it up are different. An ATOM is the smallest part of an element that can be used to make up a compound.



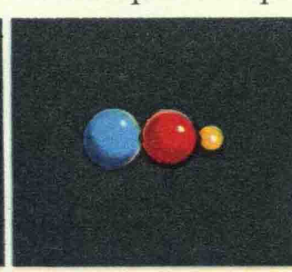
$NaCl$



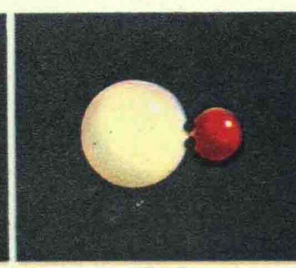
H_2O



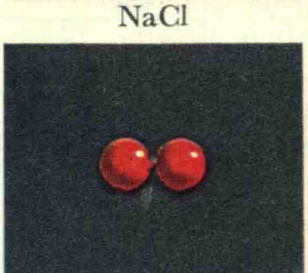
Na_2CO_3



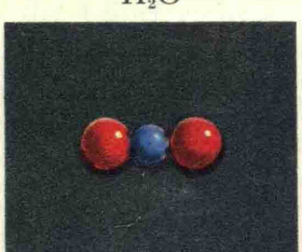
$NaOH$



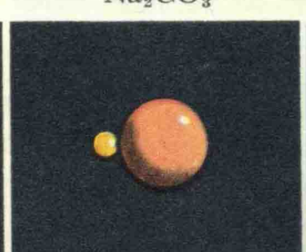
CaO



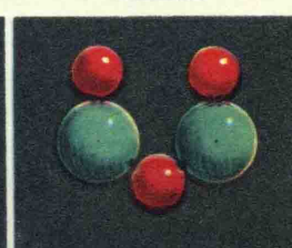
O_2



CO_2



HCl



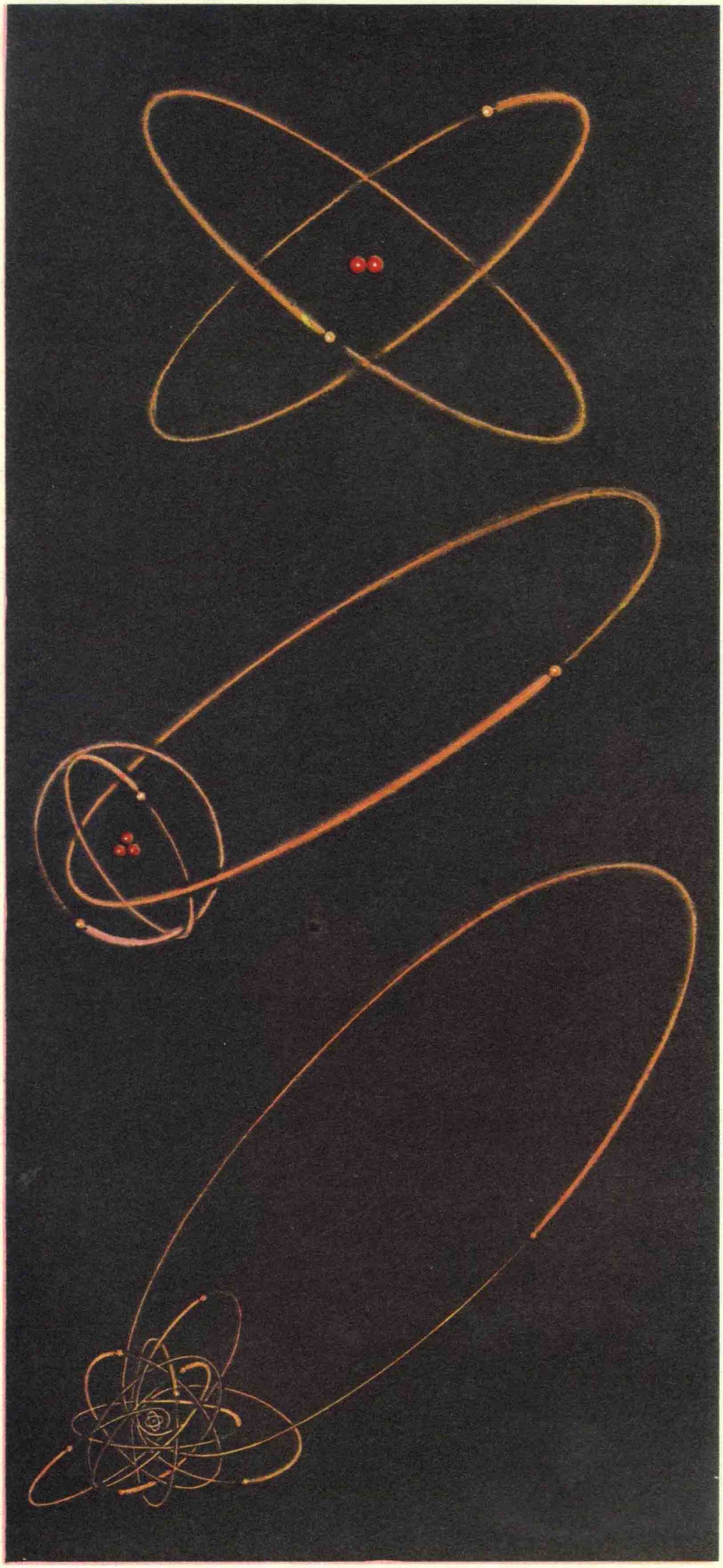
Fe_2O_3

H_2SO_4

I

II

III



Structure of Atoms

I. A MODEL OF A HELIUM ATOM. A very simple one, it consists of two plus (+positively) charged PROTONS which are the "sun" and two minus (−negatively) charged ELECTRONS which are planets.

II. LITHIUM which is the next heaviest atom, has three ELECTRONS balanced in charge by three PROTONS.

III. SODIUM is a more complex atom with eleven PROTONS balanced by eleven ELECTRONS which circulate in three orbits (shells—see Page 187).

In addition to the particles shown each of these three atoms has a number of neutrons in the nucleus. Helium has two, Lithium four and Sodium twelve.

Why do the elements each weigh a different amount? Because of the way they are formed and because the atoms of the different elements weigh different amounts.

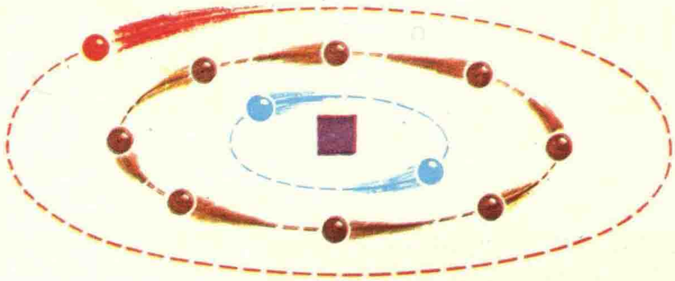
The nucleus of the hydrogen atom merely consists of one proton. To balance this there is one electron in orbit round it. Models of the structure of atoms according to Bohr's theory are all similar to the basic plan of the hydrogen atom. Each has a central positive nucleus of PROTONS, surrounded by negative ELECTRONS which move in orbits round the nucleus. Most nuclei also have neutral particles, termed NEUTRONS, in the nucleus—that is particles carrying no charge. The electron orbits are known as the "outer atom" as distinct from the "inner atom" or nucleus.

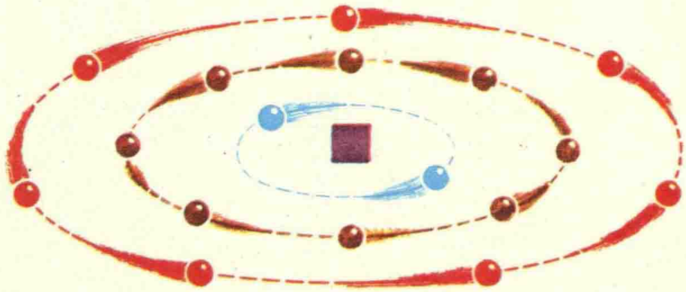
Little force is required to split off an electron from an atom, while a force many hundreds of times as large is required to split the nucleus of the atom itself.

The atomic weights and numbers of the elements reflect the number of protons, neutrons and electrons which build up their atoms. The atomic number is equal to the number of protons in the nucleus or number of electrons outside it. These two numbers are always the same. There must be enough charged electrons to balance the oppositely charged protons of the nucleus.

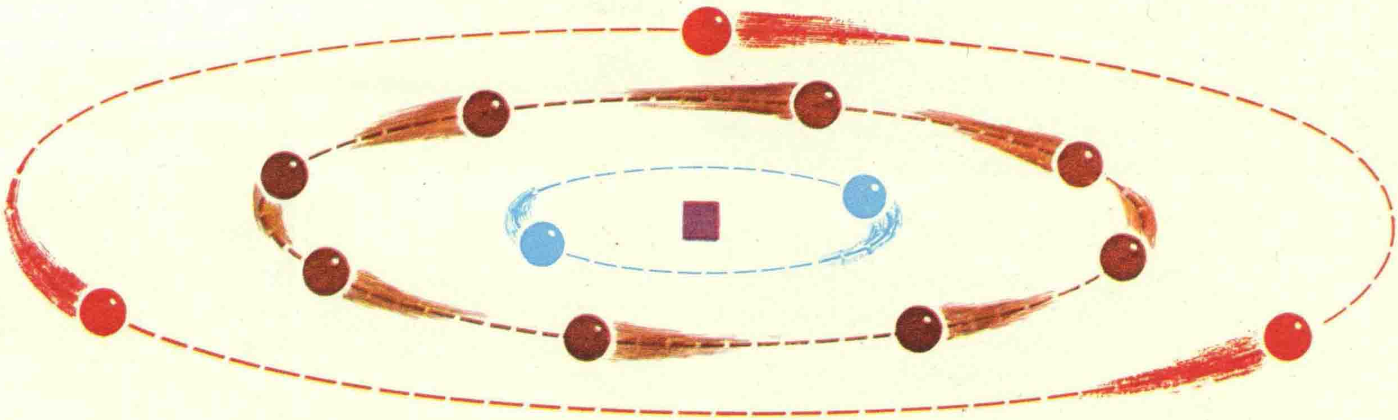
Electron Shells

If you were to draw the atoms as though the electrons moved in only one plane (as the planets move round the sun in our solar system) you would get these oblique plan views of them. These show very clearly the number of shells and electrons in them.

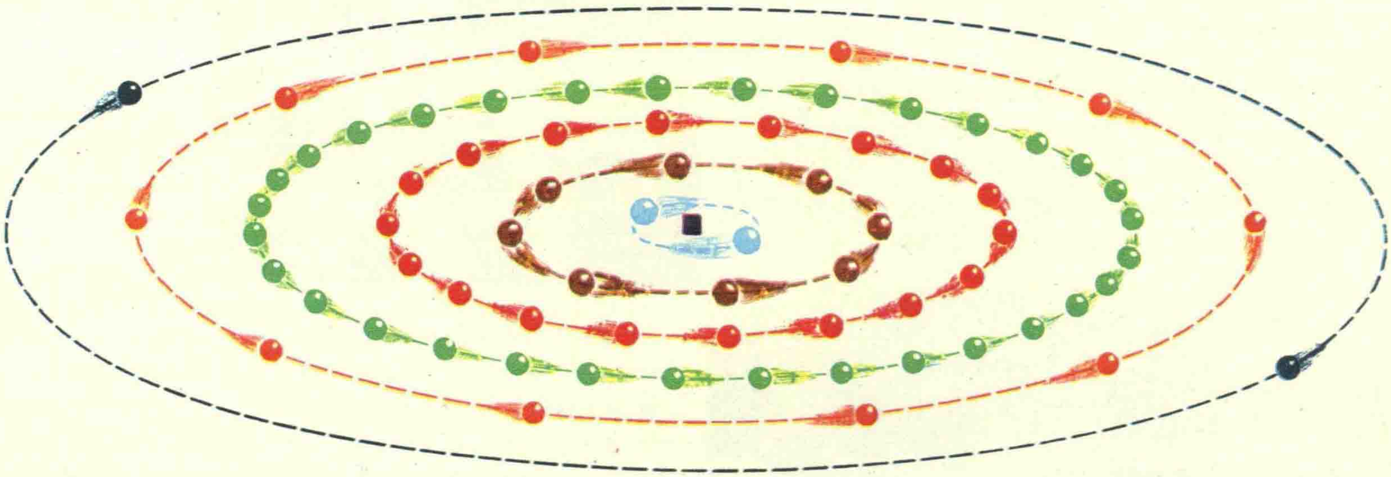




Above we see plan views of the atoms of the elements **Sodium** (*left*) and **Chlorine** (*right*), with **Aluminium** (*below*). All three elements have :— 1. A first inner shell of two electrons, 2. A second shell of eight electrons, 3. A third incomplete shell.



Hafnium (*below*) has a more complex atom with five shells altogether. The electrons in these shells, reading outwards from the nucleus, number 2, 8, 18, 32, 10 and 2 respectively.



Why elements react as they do to make compounds. The elements as they grow in number of electrons (and protons to balance) grow in regular " shells ". Sodium has only one electron in its third shell. On the other hand, chlorine has seven electrons in this shell. When elements react together they try to reach a " tidy " state of completed shells. Sodium is always trying to get rid of its lone outer electron, whilst chlorine only needs one electron to complete a shell of eight. Sodium gives its spare electron to a chlorine atom and both atoms are satisfied. Sodium chloride (common salt) is formed, a very stable compound.

Chemical Reactions

There are four main types of chemical reactions. I. Simple composition. II. Decomposition. III. Displacement. IV. Double decomposition.

In I two substances combine to form a third, while in II one substance breaks up to form two or more substances. In III one metal replaces another, and in IV two substances react with the elements changing places.

Examples:

I. $NH_3 + HCl = NH_4Cl$

II. $2HgO = 2Hg + O_2$

III. $CuSO_4 + Fe = FeSO_4 + Cu$

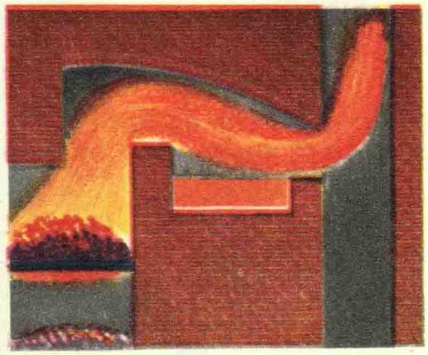
IV. $AgNO_3 + NaCl = AgCl + NaNO_3$

The illustration shows a use of displacement in printing. The plate carrying the type is coated with fine iron filings and copper sulphate on the front (*i.e.*, type face) and is then immersed in the depositing tank which contains copper sulphate and has pure copper electrodes. Copper in the copper sulphate solution is replaced by iron from the iron filings and is deposited over the plate, thus forming a hard wearing copper shell.

ACIDS AND BASES. An *acid* is a compound containing hydrogen which in aqueous solution releases hydrogen (H^+) ions.

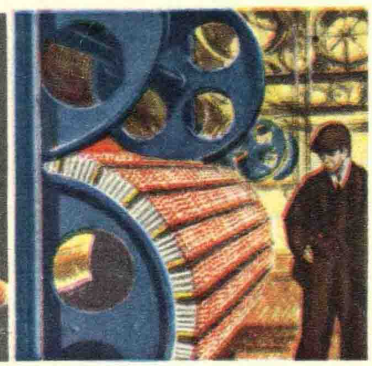
A *base* is a substance which releases hydroxyl ions (OH^-) when dissolved in water, and which reacts with an acid to form a salt.

Acids turn blue litmus red, are corrosive and often have a sour taste. Bases turn red litmus blue, and often taste bitter.



REDUCTION is removal of oxygen or the addition of electrons.
e.g., $Cu_2O + CO = 2Cu + CO_2$
In the reverberatory furnace (left) used in the thermal refining of copper, impurities are first oxidised from the copper with hot air. Poles of green wood stirred in the molten metal release gases which reduce the cuprous oxide to copper.

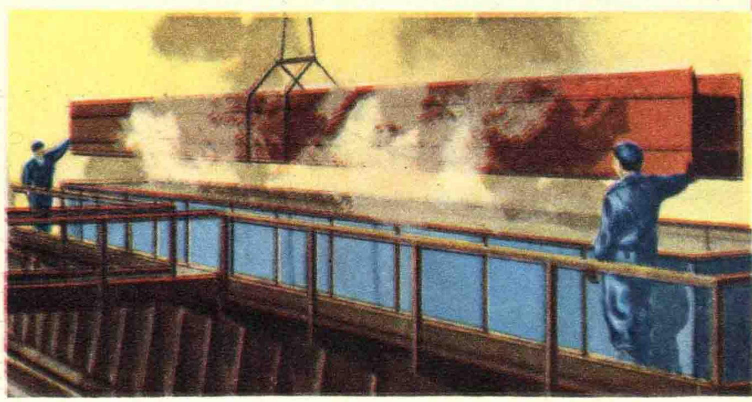
OXIDATION is combination with oxygen or removal of electrons, *e.g.*—
$4P + 5O_2 = 2P_2O_5$
phosphorous + oxygen = phosphorous pentoxide
This reaction takes place when a match is lighted. Potassium chlorate in the match-head supplies oxygen (*an oxidising agent*). (Right) Match manufacture.



Soap manufacture. Soaps are the sodium salts of fatty acids. Animal fats and vegetable oils contain esters (compounds of glycerol and an organic acid). These are boiled with caustic soda (a base) in huge vats producing soap and glycerol. The glycerol may be used in explosives while the soap is prepared for sale as tablets.

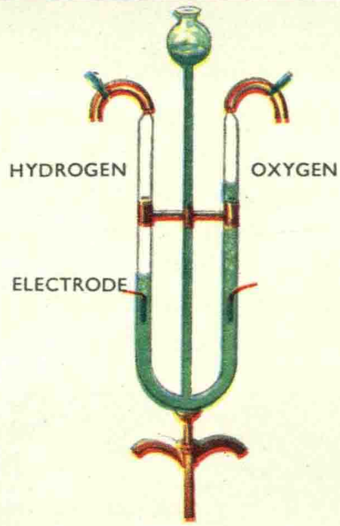
Acids on metals—when an acid reacts with a metal a salt is formed and hydrogen is often liberated from the acid.

$$\underset{\text{zinc}}{Zn} + \underset{\text{sulphuric acid}}{H_2SO_4} = \underset{\text{hydrogen}}{H_2} + \underset{\text{zinc sulphate}}{ZnSO_4}$$



Acids have many practical uses. One is the cleaning of corroded metal surfaces. Here a large steel girder is being lowered carefully into an acid tank containing sulphuric acid. The workmen are well protected against fumes and spilt acid.

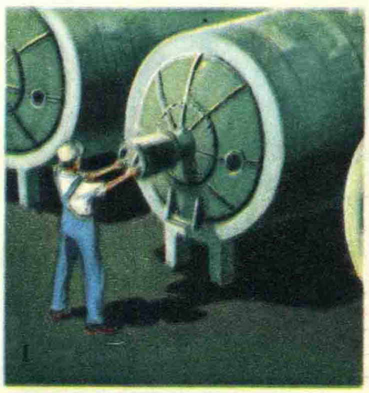
ELECTRICAL CHEMISTRY

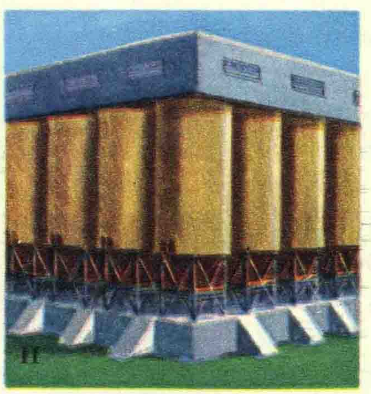


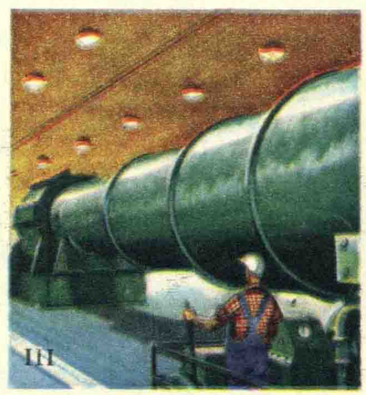
ELECTROLYSIS OF WATER

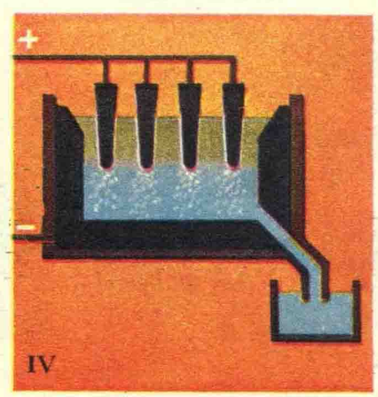
On first sight it would appear that chemistry has little to do with electricity. Chemistry, however, is the science that deals with the properties of substances, the way they react together and so on. Many substances (*e.g.*, copper) will conduct a current of electricity (*conductors*), while others (*non-conductors*) will not allow a current to pass through. These properties have important application in the use of some substances for carrying electricity and others as insulators (non-conductors). Some solutions will conduct electricity while others do not. These are respectively termed *electrolytes* and *non-electrolytes*.

When electricity is passed through a metal conductor no chemical change appears to take place. A current passed through an electrolyte solution produces definite chemical changes such as gas bubbles being given off. If an electric current is passed through water (*left*) with a drop of sulphuric acid added to make it a better conductor, it is split into hydrogen and oxygen.

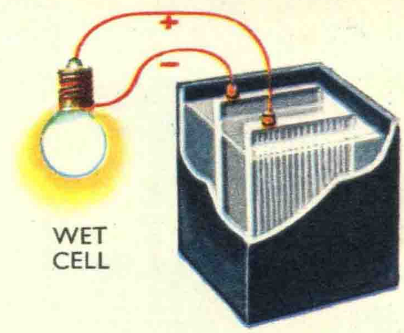




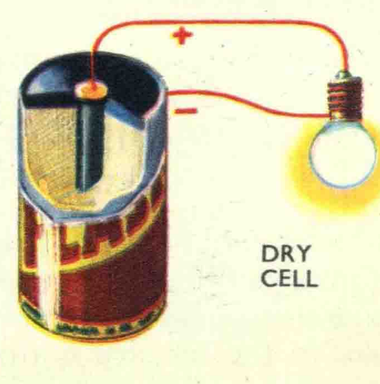




ALUMINIUM is the earth's most abundant metal. *Bauxite* and *cryolite* are the chief ores used in its production.
Bauxite ($Al_2O_3.2H_2O$—hydrated aluminium oxide) is the primary raw material used in its manufacture. This is crushed, roasted, and mixed in pressure tanks (**I**) with hot caustic soda at 150°. Aluminium oxide from the bauxite is dissolved forming soluble sodium aluminate. ($Al_2O_3 + 2NaOH \rightarrow 2NaAlO_2 + H_2O$). Insoluble impurities (*e.g.*, Iron oxide) are removed by filtration. (**II**) Precipitation. A little fresh aluminium hydroxide is added to the aluminate in tall tanks. Aluminium hydroxide separates out. After cooling and crushing, this is dried in long, revolving drums (**III**) leaving a white powder of aluminium oxide. The aluminium is then obtained electrolytically in a large cell (**IV**) which is an iron box lined with carbon as the cathode, and containing molten *cryolite* ($AlF_3.3NaF$) and *fluorspar* (CaF_2) as the electrolyte. When carbon rods are lowered into this the aluminium separates out at the cathode and is tapped off from time to time.



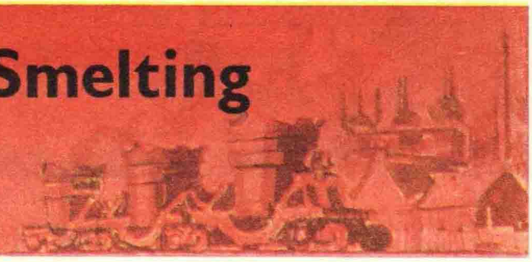
WET CELL

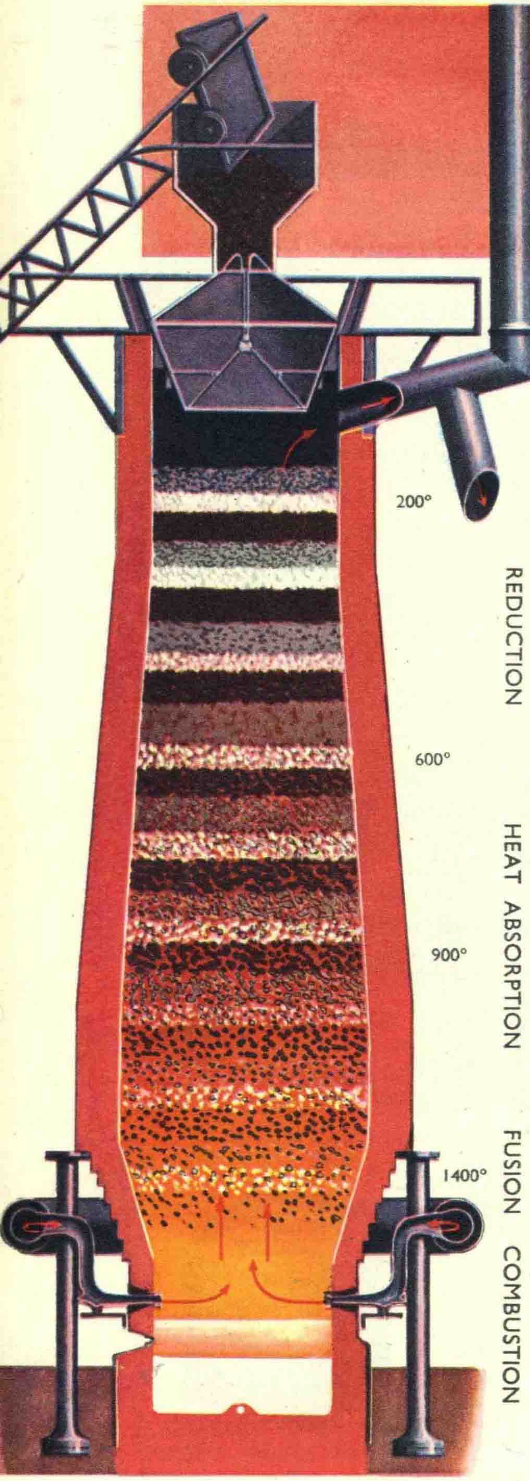


DRY CELL

If two plates of unlike metals are immersed in an electrolyte solution and connected by a wire, an electric current will flow along the wire. This is the basis of the simple cell.
Cells are of two types, *primary* and *secondary* cells. The dry cell is an example of a primary cell, while the accumulator is typical of secondary cells. It does not store electricity, it stores potential chemical energy which can be changed into electrical energy. The chemistry of cells will be discussed on Page 203.

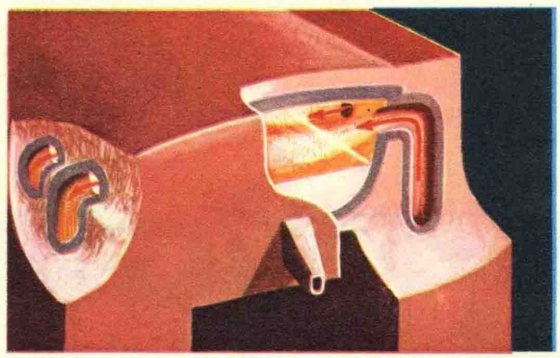
Refining and Smelting of Metals



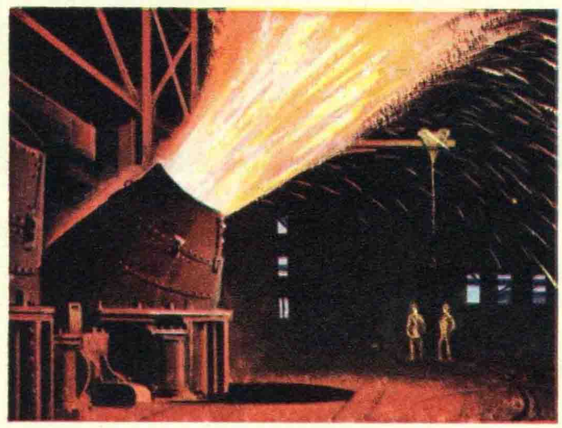


Iron is found in small quantities almost the whole world over. The main ores used for its commercial production are *magnetite* (Fe_3O_4) and *haematite* (Fe_2O_3). The ores are first roasted to drive off carbon dioxide and water, to burn impurities such as arsenic and sulphur, and to convert the ferrous oxide to ferric oxide. This prevents damage to the furnace lining occurring later due to slag (waste) formation, and makes the ore spongy so that it is easier to reduce to metallic iron.

The *Blast furnace* is where this reduction occurs. It has a thick brickwork lining to withstand the great heat of the process. At the start of the operation a blast of hot air is blown into the bottom of the furnace. The ore, limestone, and solid fuel is fed into the furnace at the top and as it sinks gradually towards the furnace base becomes hotter and hotter, many chemical changes taking place. The result is that iron oxide is reduced to iron which collects in a molten state at the bottom of the furnace and is run off from time to time into sand moulds where it solidifies as *pig-iron*. Many impurities are burnt but pig-iron contains carbon, silicon, phosphorus and sulphur.

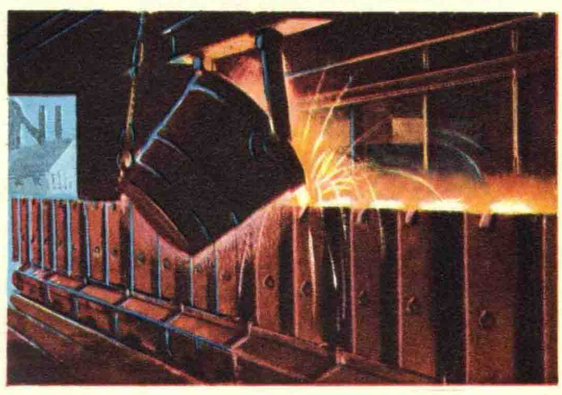


OPEN HEARTH FURNACE



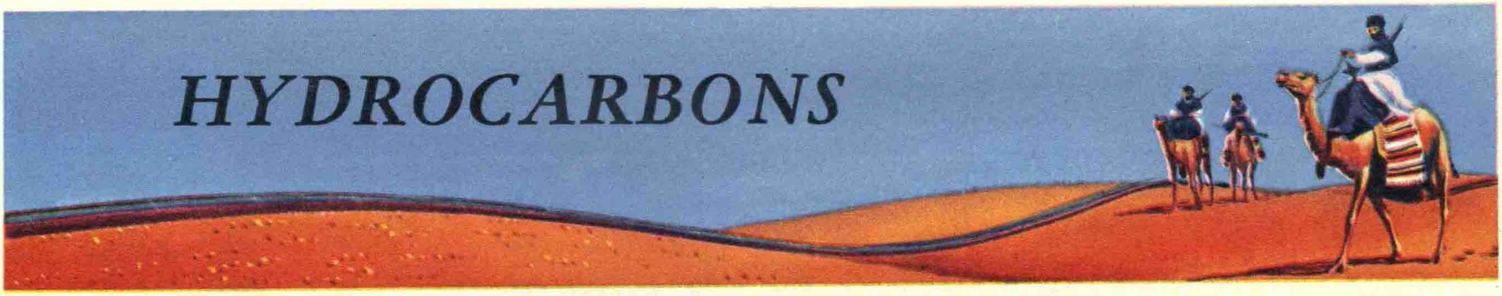
BESSEMER CONVERTER

Most of the iron produced in industry is converted to *steel* which contains about 1–2 per cent. of carbon. The *open-hearth* process is mainly used nowadays. Pig-iron, haematite, and scrap-steel are put into the hearth. It is heated by producer gas (carbon monoxide) which is blown alternately from holes on both sides of the chamber. Sulphur and ferric oxide are removed by adding ferromanganese. In the *Bessemer* process air is blown through holes in the furnace bottom into the molten pig-iron. In both processes the steel is poured into moulds.



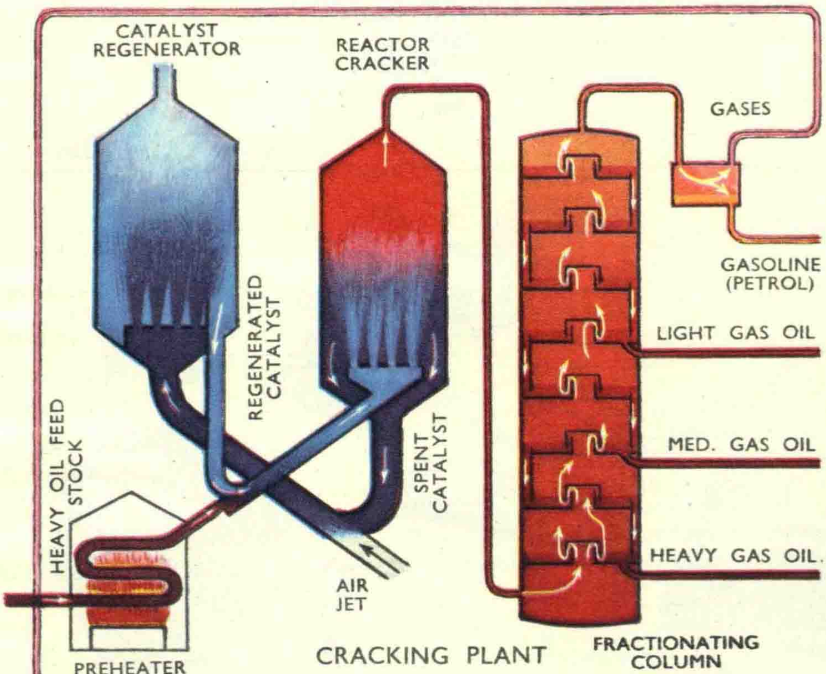
POURING STEEL INGOTS

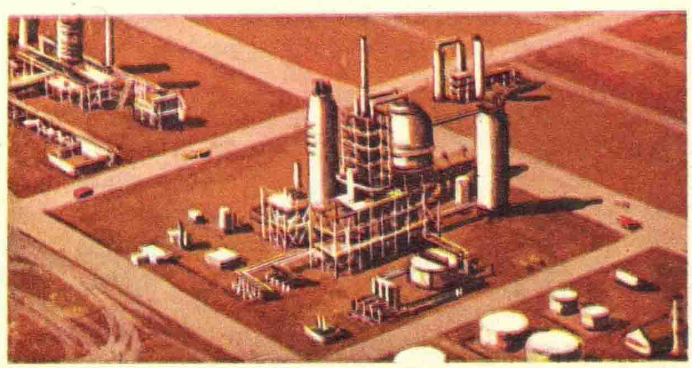
HYDROCARBONS



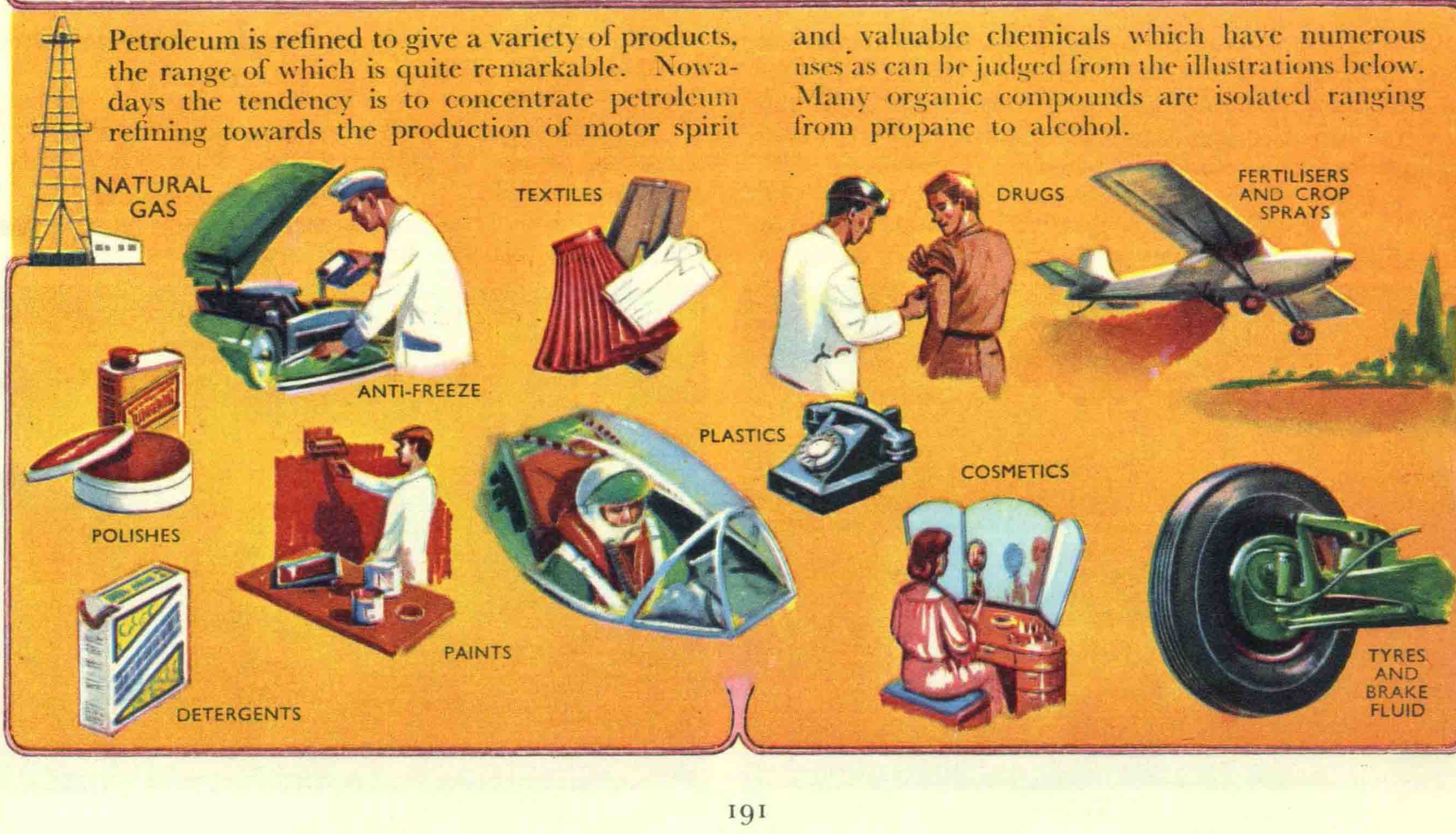
Hydrocarbons are compounds which contain only the elements carbon and hydrogen. Carbon compounds are divided into two main groups, aliphatic and aromatic forms. Both these groups contain hydrocarbons. Aliphatic hydrocarbons include the paraffins, olefines and acetylenes, and aromatic hydrocarbons include benzene, toluene, naphthalene and anthracene.

Petroleum manufacture. Petroleum is a mixture of hydrocarbons. In nature it is a dark oily substance, and is obtained by pumping it from deep in the ground. The crude petroleum is heated and its various constituents turn into vapour at different temperatures in the condenser. These are separated and distilled in the refining process. " Cracking " converts heavy oils into petrol and light naphthas.





Petroleum is refined to give a variety of products, the range of which is quite remarkable. Nowadays the tendency is to concentrate petroleum refining towards the production of motor spirit and valuable chemicals which have numerous uses as can be judged from the illustrations below. Many organic compounds are isolated ranging from propane to alcohol.

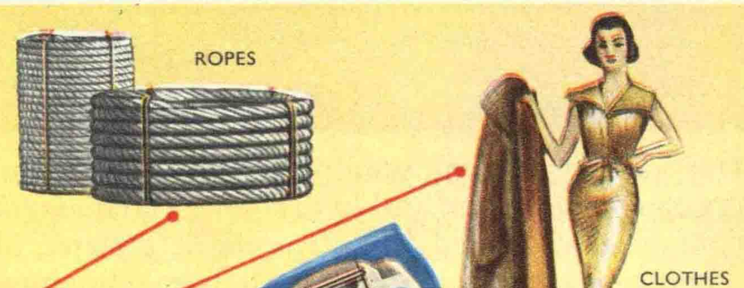


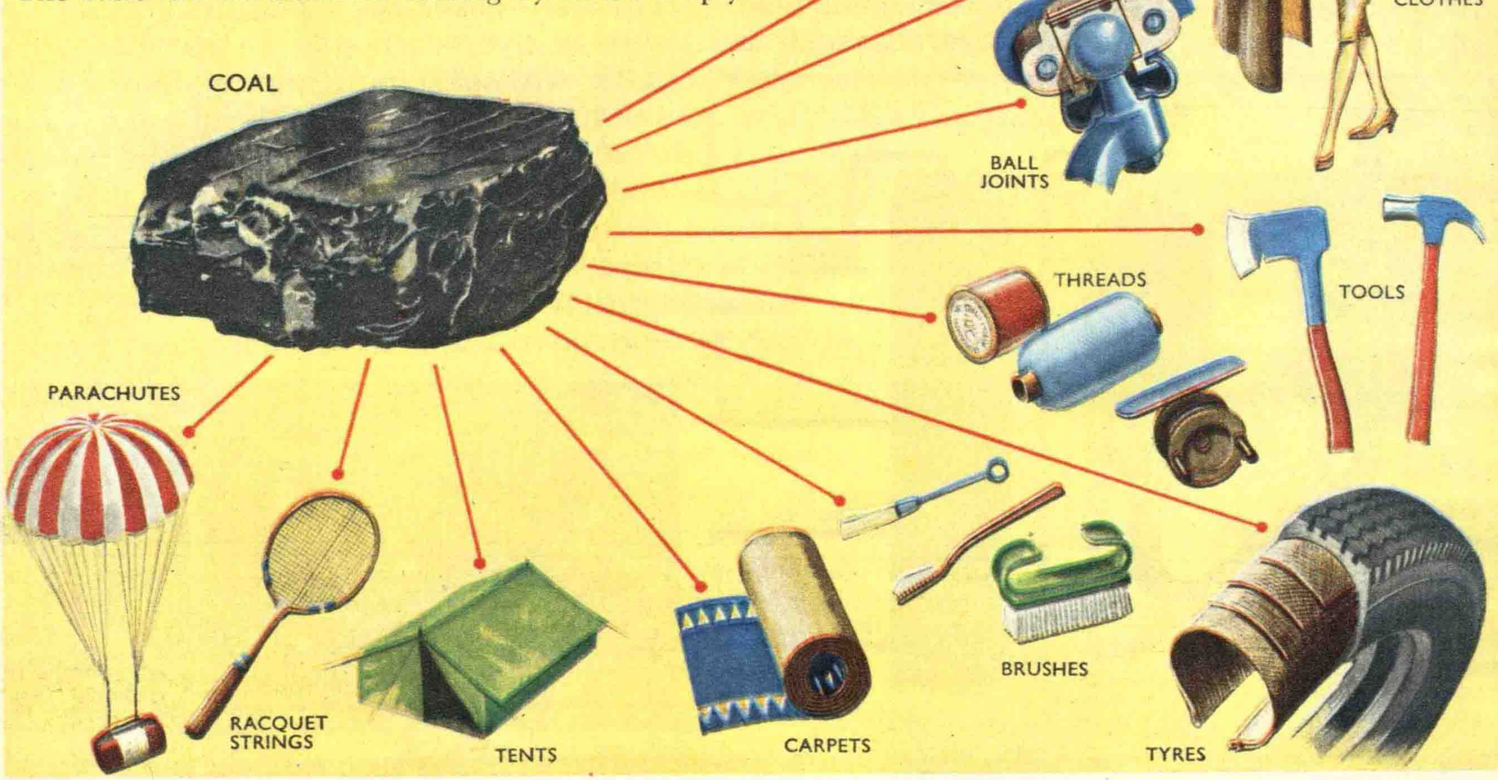
Nylon and other Plastics

NYLON FROM COAL

Nylon is one of the most widely used synthetic products. The range of articles made from it is incredibly numerous ranging from fine thread to thick, tough ropes, ball joints to toothbrushes, and crash helmets to parachutes and tents.

The basic raw materials for making nylon are simply





coal and air. From these abundant materials phenol and ammonia are made, and then by a series of complicated chemical reactions long chain molecules are built up until finally nylon is obtained. The process of building up these large molecules is known as polymerisation. The raw nylon is extruded through small holes to produce thread, or moulded to shape required.

PLASTICS. Besides nylon there is a wide range of plastics including polythene, perspex, cellulose forms (*e.g.*, celluloid), and vinyls.

The pictures below show the final stages in making some plastics goods. The machine is a compression moulding press. A plastic powder is poured into the heated mould (left) which is in two halves. When the mould is closed the terrific pressure exerted converts the powder into the finished articles.

THE WORK OF THE CHEMIST

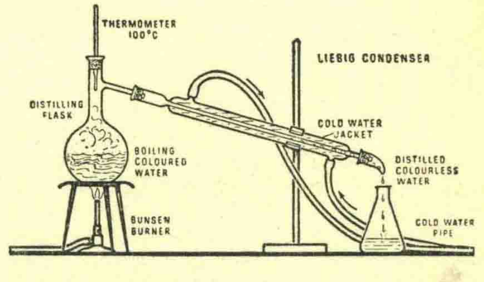
When we speak of a chemist, our mind probably runs to the man who makes up our medicine in the local chemist's shop. In the sense that he is using chemicals in his medicines he is a chemist right enough, but chemistry is only one of many special skills he needs for his work. He is more correctly described as a pharmacist—the letters M.P.S. (Member of the Pharmaceutical Society) show that he has qualified to do this work.

The chemist of whom we are writing in this section has a different type of interest. He concerns himself with the nature of a substance—of what other substances is it made, how much of each is present, and how they are joined together. He carries out experiments, such as heating a single substance, mixing substances together, passing an electric current through them, and so on. He finds out in his laboratory suitable methods for making useful substances and puts them into practice on a large scale for manufacture in a factory. Plastics, dyes, vitamins and artificial rubber are common examples of the chemist's inventive skill. *Synthesis* is the word used for the process of building up these new complicated materials from simpler substances. Other chemists take complicated substances apart—*analysis* is the name given to this. A chemist will analyse milk, ice-cream, sausages, butter and many other edible things to make sure that the public is receiving pure goods; he will analyse the coal, iron, steel and other materials delivered to a factory, and also the goods produced by the factory. He may even work in a police laboratory and, for example, analyse a smear of paint on a suspect's clothing to prove it identical with the paint in the room in which a crime was committed.

The careful chemist is always at pains to purify the substance with which he is dealing. His job is to observe and to report on its properties; and if other substances are present, how can he know if the properties he reports on are those of the substance itself or of its impurities? There are many methods employed in purification: let us consider a few of the simpler ones.

DISTILLATION

This is a good method for obtaining a pure liquid from a solution; for example, pure water or "distilled" water from tap water, or pure water from sea water. The liquid is heated until it boils, i.e. changes into vapour. The vapour is led away (leaving the solid behind) and cooled, thus producing the liquid in a separate vessel.



The Liebig condenser, a common type of apparatus for distillation used in the laboratory. To purify water containing an impurity, the liquid is heated in the distilling flask to boiling point, when it vaporises. The vapour is led through a long glass tube which is enclosed by another tube in which cold water is circulating. In passing through the inner tube the vapour is condensed to pure distilled water.

Shipwrecked sailors may have to wait many days before rescue and often suffer badly through lack of fresh water. With an apparatus similar in principle, fresh drinking water can be distilled from sea water for as long as floating wreckage or driftwood is available for stoking the boiler.

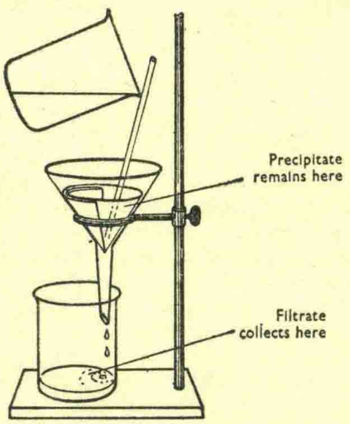
Distillation may also be employed to separate one liquid from another, since every pure liquid has a definite boiling point, at which temperature it turns into vapour. Thus if liquids of boiling points 80°C. and 100°C., respectively, are mixed and the mixture is heated to 80°C. a great deal of vapour will come off and be condensed. This will be the liquid of b.pt. 80°C., and most of it will be recovered in this way. As the temperature is raised above 80°C. very little vapour will come off until the temperature reaches 100°C., when the bulk of the second liquid will vaporise and may be condensed and collected. Note: in distillation the bulb of the thermometer is in the vapour and not in the liquid, since the temperature of the vapour will indicate the nature of the substance being given off, and not the temperature of the mixture.

The separation of crude oil into its various "fractions" by distillation is an important industrial application of this method. Crude oil, as it comes from the earth, is a mixture of a very large number of different chemical substances. No attempt is made to separate out the pure substances—all that is done is to provide various mixtures of oils, all of which boil within a narrow range of temperatures.

The liquids which are collected first are those with the lowest boiling points, and those which boil off and condense last are those with the highest boiling points.

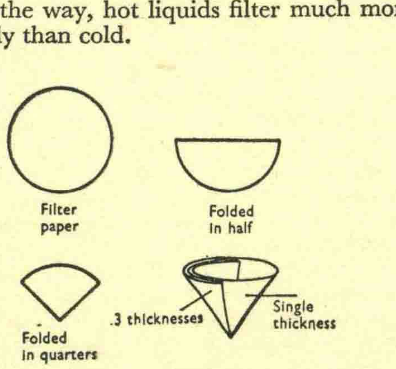
Petrol is a mixture of liquids of low boiling points, e.g. from 20°C. to 200°C.; paraffin oil (kerosene) is a mixture of liquids boiling between 150°C. and 300°C.; gas oil is made up of liquids boiling above 250°C.

FILTRATION



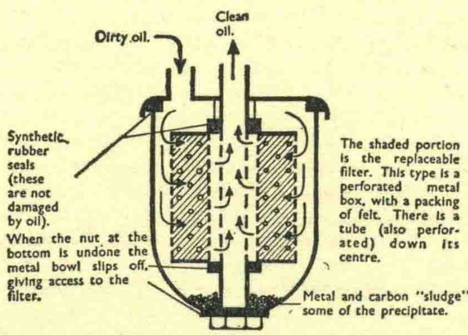
Filtration is the method used to separate a solid from a liquid, say sand from water. In the laboratory a funnel, of glass or plastic, and a circular piece of porous paper (just like blotting paper) are used. The solid remains on the paper and is called the *precipitate*: the clear liquid drips from the funnel and is called the *filtrate*.

By the way, hot liquids filter much more quickly than cold.



Note how the filter paper is folded and placed in the funnel to make a conical container. It is gently smoothed to the exact shape of the funnel and then wetted, to keep it in place. If the liquid is poured down a glass rod and the stem of the funnel touches the inside of the collecting vessel (a beaker) there will be no splashing.

You will probably find a filter at work if you are allowed to examine a recently manufactured motor-car engine. A gallon or more of oil is continuously pumped around the engine to keep this properly lubricated. The oil, in its travels, picks up tiny pieces of metal, which come away from the engine as it wears, and specks of hard carbon, which are formed when petrol burns. These substances might easily damage the engine, so on its journey through the engine the oil is filtered through a special filter (often a metal sieve) to remove all solid impurities. This filter costs only a few shillings and the wise motorist throws it away and puts in a new one long before there is any risk of it becoming blocked with solid.

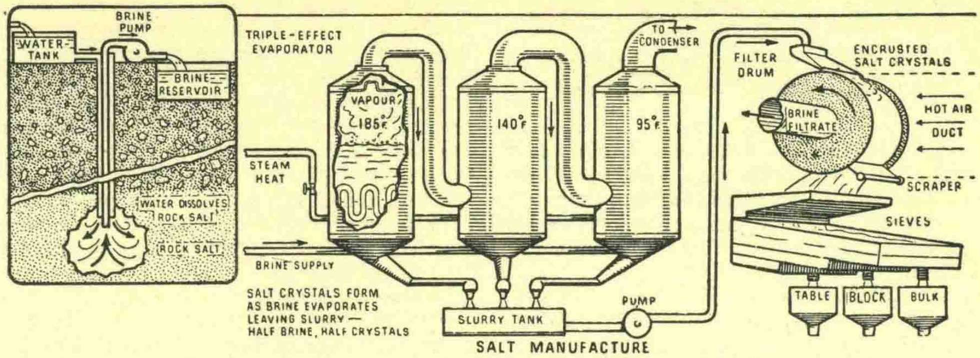


The principle of a motor-car engine oil filter

CRYSTALLISATION

If you take some water and a substance which will dissolve in it, like sugar, you will find that there comes a point when no more sugar will dissolve, no matter how much you stir. The solution has become *saturated.* However, when the water is warmed, more sugar will now dissolve. The hotter the water, the more sugar it will dissolve before becoming saturated.

A hot solution of sugar contains much sugar—the cold solution can contain much less because it takes less sugar to "saturate" the solution. Therefore, when the hot solution cools there is less and less "room" for the sugar in solution, so the excess has to come back to the solid form, as crystals. Each substance has its own particular shape of crystal—the angles between the sides, for example, are reproduced with remarkable accuracy. The usual way of preparing crystals in a laboratory is to boil the solution, driving off some of the water as steam, and to test frequently with a glass rod dipped in the liquid. As soon as the solution is saturated, the smear of wet on the rod clouds over (the formation of crystals) as it begins to cool. The solution is then covered, to keep out dust, and allowed to stand undisturbed. As it cools down, and later loses more water by evaporation, crystals form in the solution. The liquid in which the solid dissolves is called the *solvent,* the solid which dissolves in it is the *solute,* and the result is a *solution.* The liquid left after the crystals have formed is called the *mother liquor.*



A salt well (left). Water is forced down the outer pipe and the saturated solution of brine obtained is pumped to the surface up the inner pipe, the salt being recovered by evaporation. After the brine has been filtered to remove impurities it is evaporated in the "triple-effect" evaporator (centre) consisting of three vessels, through which the vapour passes in turn. Salt crystals are formed, and are drawn off in the form of a slurry. The slurry is then passed over a rotating drum (right) covered with fine mesh. Hot air is forced through the slurry and dries it until it forms a cake of salt. This is then removed from the drum by scraper knives. It is sieved to grade it into finest table salt, less fine crystals, and the largest crystals for bulk supplies.

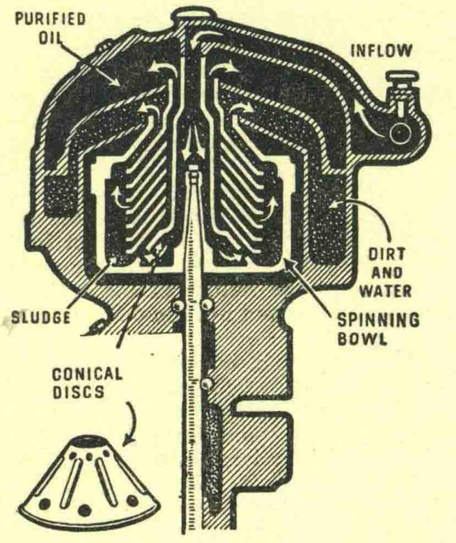
Crystallisation from water is one of the methods used to purify sugar, the type of sugar obtained depending very largely upon the skill of the "sugar boiler", the man who decides exactly when to turn off the heat and to allow crystallisation from the sugar solution to begin.

The manufacture of table salt, cooking salt and coarse salt is another good example of crystallisation. Rapid cooling of a solution produces small crystals; slow cooling and slow evaporation give large crystals.

Different solids have different solubilities in water, and use is made of this in *fractional crystallisation,* in which the least soluble solid crystallises out and leaves the other in solution.

CENTRIFUGING

You have probably noticed the tendency of a rapidly rotating object to move outwards —the stone swung around on a piece of string is but one example. The heavier the object and the faster the speed, the greater is the effect. If, then, a light liquid contains particles of a heavy solid, and it is whirled around in a *centrifuge,* the solid is flung out more than the liquid, and may be found tightly packed in the bottom of the special glass tube in which the liquid is whirled around. The trouble with this method is that a succession of tubes has to be filled up and whirled around separately to deal with a reasonable volume of liquid. Continuous-flow centrifuges are available in which the heavy particles are flung outward by spinning discs. If you spend your holiday on a farm you may find the farmer using a similar machine to separate the lighter cream, which he sells, from the heavier skimmed milk, which he gives to his pigs.



Heavy-grade fuels on oil-fired ships have their impurities removed by a form of separator which employs centrifugal force. Just as gravity causes sediment to settle to the bottom of a fluid, centrifugal force separates sediment more rapidly—but in a horizontal direction. As the fuel is rotated rapidly in the separator, the heavier particles slide along the under sides of the conical discs until they reach the sludge space, while the lighter part —pure oil—tends to move towards the centre of the bowl, guided by the sloping discs.

PROPERTIES OF CHEMICALS

A pure chemical is recognised by its properties—e.g. its colour, its smell, its specific gravity, its boiling point and so on. All these are called *physical properties,* since they can be studied without altering the composition of the original substance. The *chemical properties* are those which are observed when the original substance breaks up into other simpler substances, or perhaps joins up with some other substance to make a more complicated one. Here are some of the *physical* properties of coal: it is black and shiny in appearance; it is insoluble in water; it sinks in water, therefore it is denser than water; it is easily broken, i.e. brittle. None of the above observations alters the nature of the coal—it is still coal after each test.

When heated, however, coal gives off gas and leaves an absolutely new substance, coke. It has completely changed its nature, so the heating of coal is a *chemical* change; and when coal is heated a *chemical* action has been observed.

Man has always been curious concerning the things around him in nature, and there is little doubt that experiments have gone on right from his early days. It is likely that many of the advances made by our ancestors were the result of lucky chance discoveries; e.g. the making of glass, the production of iron and bronze from their ores (see page 190), and the discovery of gun-powder. There was little understanding of *why* a process worked, and along with the few useful discoveries were a very large number of chemical recipes and ideas which seem nonsense to us today.

During the last two hundred years experiments have become more exact, and more serious thought has been given to the results. In particular, careful weighing and careful measurement of the volumes of gases involved in chemical reactions have led to important results. These results can be summed up in a few basic chemical laws, which are quoted below. In these laws the word "*element*" is applied to a simple substance which cannot be broken up into any simpler substances. Copper, iron, gold, silver and mercury (the "quicksilver" of a thermometer) are examples of elements of which we now know over a hundred. "*Compounds*" are groups of elements combined together to form absolutely different substances. To give only one startling example, the salt you use at the dinner table (sodium chloride) is made up of a metal, sodium, which melts (and can even catch fire) when it falls into cold water, and a green gas, chlorine, which is deadly poisonous. Nobody but a lunatic would put either sodium or chlorine into his mouth, yet common salt is harmless.

THE LAWS OF CHEMISTRY

LAWS OF COMBINATION BY WEIGHT

The Law of Indestructibility of Matter

There is no change in weight in any chemical reaction so long as account is taken of all the substances taking part in the reaction and of all those formed. In other words, matter (substance) cannot be created or destroyed—it can only be changed.

It is difficult to believe that nothing is lost when a firework weighing a couple of pounds goes off and leaves behind a few scraps of paper. Yet if special arrangements are made to keep back all the gases which are formed, and to allow for any air used up, the law *is* found to be true.

If 12 lb. of anthracite (carbon) are burned in the kitchen boiler, the result is 44 lb. of gas—12 lb. from the carbon and 32 lb. from the air.

So 12 lb. of carbon + 32 lb. of gas from the air = 44 lb. of a gas called carbon dioxide.

The Law of Constant Composition

No matter how a certain chemical compound is produced, it will always contain the same elements, united in exactly the same proportions by weight.

The black solid which forms under the bottom of Mother's copper kettle is "copper ash" or, to give it its old name, "calx of copper". Pure specimens of this substance can be gathered from all over the world, and it can be made in the laboratory in a dozen different ways, starting in each case with a different specimen of copper. No matter its source or the method of making, the "calx of copper" a'ways contains 4 oz. of copper to 1 oz. of oxygen. (We now call "calx of copper" black copper oxide.)

In the "calx of mercury", a bright red powder, we find, always, that 201 oz. of mercury are combined with 16 oz. of oxygen. (We now call "calx of mercury" mercury oxide.)

The Law of Multiple Proportions

Elements sometimes combine in different proportions to form different compounds. When this occurs, the weight of one combining with a fixed weight of the other are simply related.

Example:

The black "calx of copper" and the brown "calx of copper" give the following results when split up (decomposed, or analysed):

Compound	Weight of Copper (oz.)	Weight of Oxygen (oz.)
100 oz. black copper oxide.	80	20
100 oz. brown copper oxide.	88·9	11·1
Simplifying: Black copper oxide.	4	1 } a fixed weight.
Brown copper oxide.	8	1
Simplifying still further: Black copper oxide. Brown copper oxide.	4 and 8 are in the same proportion as 1 and 2, a very simple relationship indeed.	

The Law of Reciprocal Proportions

When an element A combines with an element B to form one compound, and combines separately with element C to form another compound, then the weights of B and C, which combine with a fixed weight of A, are either the same as, or simply related to, the weights of B and C, which will combine together.

(*a*) *A simple, made-up illustration.*

1 gm. of A combines with 2 gm. of B to form compound X.

1 gm. of A combines with 3 gm. of C to form compound Y.

2 gm. of B combines with 3 gm. of C to form compound Z.

(*b*) *An actual example.*

1 gm. of hydrogen combines with 16 gm. of oxygen (hydrogen peroxide).

1 gm. of hydrogen combines with 16 gm. of sulphur ("rotten-egg gas").

16 gm. of oxygen and 16 gm. of sulphur combine together (sulphur dioxide). (Same proportion.)

(*c*) *Another actual example.*

1 gm. of hydrogen combines with 8 gm. of oxygen (water).

1 gm. of hydrogen combines with 16 gm. of sulphur.

16 gm. of oxygen and 16 gm. of sulphur combine together.

8: 16 is not the same as 16: 16, but as 8 = half 16, there is a *simple relationship.*

Thus, by 1800 or thereabouts chemical experiments with weighings had yielded many results, which were collected together and summarised in the four laws of combination by weight. People now knew *what* happened: if only they could understand why!

John Dalton, a Manchester schoolmaster, between 1802 and 1808 put forward an idea, or *theory*, which made it possible to understand how chemical actions occurred, and also to explain the laws of combination. To be quite truthful, Dalton's ideas had to be altered slightly during the following half-century in order to explain all the chemical actions then known, but to Dalton the main credit must go. The modified *Dalton Atomic Theory* is summarised below (including a few ideas not introduced by Dalton).

1. Every element is made up of atoms.
2. An atom is the smallest particle of an element that it is possible to obtain.
3. The atoms of different elements are different in weight and in other respects.
4. All the atoms of one particular element are exactly the same in every respect.
5. When chemical combination occurs, small whole numbers of atoms of different elements combine together, e.g. 1 atom of element A combines with 1 atom of element B, or perhaps 2 atoms of element C combine with 3 atoms of element D.
6. Although chemical reactions take place between atoms, both elements and compounds *exist* in little clusters of atoms called molecules.
7. All the molecules of one particular element or compound are alike, but quite different from the molecules of other elements or compounds.

Molecules are extremely tiny things; it is estimated that there are in a single drop of water more molecules than there are people on the whole of the earth.

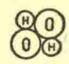
Let us see how Dalton's Atomic Theory can explain the laws of combination by weight.

First the Law of Indestructibility of Matter. In a chemical reaction molecules split up into atoms and the atoms recombine in different groups, i.e. new molecules. All the atoms there at the beginning are accounted for at the end—so there can be no change in the total weight.

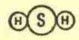
Secondly, the Law of Constant Composition. The molecule of black copper oxide contains one atom of copper and one of oxygen. So every specimen of black copper oxide, no matter where it is mined or how it is prepared, contains copper and oxygen atoms in equal numbers. Since all copper atoms are identical and all oxygen atoms are exactly alike, the proportion by weight of copper to oxygen must be always the same, i.e. the weight of one copper atom compared with the weight of one oxygen atom.

Thirdly, the Law of Multiple Proportions. All the molecules of one compound of copper and oxygen, black copper oxide, contain one atom of oxygen and one of copper. The molecules of brown copper oxide all contain two atoms of copper and one of oxygen. Remembering that all copper atoms are exactly alike and that all oxygen atoms are identical, clearly there must be double the proportion of copper in the brown copper oxide that there is in the black copper oxide.

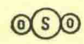
Lastly, the Law of Reciprocal Proportions. We might think of the molecule of hydrogen peroxide like this:



and of the "rotten-egg gas" (hydrogen sulphide) as:



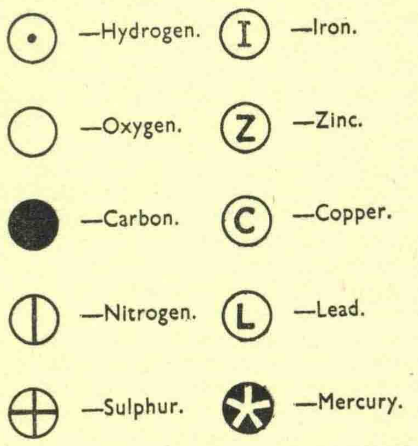
The molecule of sulphur dioxide, the gas formed from sulphur and oxygen, is:



that is, the very atoms of sulphur and oxygen which combined separately with a couple of atoms (the fixed weight) of hydrogen.

If you think of all molecules in chemistry rather like Meccano models, all built up from about a hundred standard parts (the different sorts of atoms), you will have a very good idea of what happens in chemistry. We are limited by the parts we have in our Meccano kit (matter cannot be created). Extremely elaborate models can be built up (synthesis of molecules) and then taken to pieces (decomposition). We can use the parts from one model to make other models (molecules indulging in chemical action to form new molecules). Since every part is turned out by machine it is identical with every other specimen of the same part, no matter where it is bought, so the laws of combination by weight apply to our Meccano models exactly as they do to our chemical molecules.

JOHN DALTON'S CODE FOR ATOMS
No longer used.



LAWS OF COMBINATION BY VOLUME

Just as coincidences had been noticed when exact weighing was introduced to chemical observations, so similar coincidences came to light when the volumes of gas taking part in a chemical reaction were carefully measured. The volume of a gas changes considerably when its temperature changes or when the pressure upon it is altered, so special care must be taken to play fair and to measure the volume of every gas concerned at exactly the same temperature and pressure. The agreed standard temperature is 0°C., and the agreed standard pressure is that of the air when the barometer registers 76 cm. of mercury. 0°C. and 76 cm. of mercury are therefore called "Standard temperature and pressure" (S.T.P.). The abbreviation N.T.P. (for "Normal Temperature and Pressure") is also often used, and refers to exactly the same conditions.

Here are a few examples of the results which are obtained.

(*a*) 1 pint of hydrogen combines with 1 pint of chlorine to form 2 pints of hydrochloric acid gas.

(*b*) If 100 c.c. of ammonia gas is split up, the result is 200 c.c. of gas, which is found to consist of 150 c.c. of hydrogen and 50 c.c. of nitrogen.

(*c*) A piece of sulphur (we do not measure the volume of this as it is a solid and not a gas) burns in 1 litre of oxygen and produces exactly 1 litre of sulphur dioxide gas.

These "coincidences", discovered by experiment, were expressed by Gay Lussac in his *Law of Combining Volumes*, which states:

When gases react together their volumes are simply related to each other and also to the volumes of the products, if these are gases. (Provided, of course, that all volumes are measured under the same conditions of temperature and pressure.)

Dalton's Atomic Theory explains the Laws of Combination by Weight very effectively. Can it, perhaps, also explain the Law of Combination by Volume? The clue was provided by Amadeo Avogadro, an Italian, who put forward the following theory, known as Avogadro's Hypothesis:

In a fixed volume of every gas (under the same conditions of temperature and pressure, of course) there existed exactly the same number of molecules. He put forward this suggestion in 1811: it has stood the test of nearly 150 years, so it is almost time it was promoted to Avogadro's Law! (*Note.* A "hypothesis" is a suggested explanation—something perhaps worth testing; a "law" is accepted as a true explanation.)

The connection is easy to understand.

From the atomic theory we believe that 1 molecule of hydrogen combines with 1 molecule of chlorine to form 2 molecules of hydrochloric acid gas.

Let us suppose there are x molecules of hydrogen in a pint of hydrogen. We already know that x molecules of hydrogen combine with x molecules of chlorine to form $2x$ molecules of hydrochloric acid gas. But, if Avogadro's Hypothesis is true, there will be x molecules of chlorine in a pint of chlorine and $2x$ molecules of hydrochloric acid in 2 pints of hydrochloric acid gas. So x molecules of hydrogen $+$ x molecules of chlorine$=2x$ molecules of hydrochloric acid gas can be written as 1 pint of hydrogen $+$ 1 pint of chlorine $=$ 2 pints of hydrochloric acid gas, which is exactly what has been found by experiment.

Jöns Berzelius, of Stockholm, suggested a new code to represent atoms, the one which replaced Dalton's and is still in use today. In it the *atom* of an element is represented by a capital letter or a group of two letters, the second being a small letter. Here are a few examples.

BERZELIUS' CODE FOR ATOMS	
H	an atom of hydrogen.
O	an atom of oxygen.
N	an atom of nitrogen.
C	an atom of carbon.
S	an atom of sulphur.
Cl	an atom of chlorine.
I	an atom of iodine.
Fe	an atom of iron.
Cu	an atom of copper.
Ag	an atom of silver.

This system was also extended to molecules, a small number following the code symbol showing the number of atoms present.

BERZELIUS' CODE APPLIED TO MOLECULES	
H_2	Molecule of hydrogen (it contains 2 atoms).
O_2	Molecule of oxygen (it contains 2 atoms).
N_2	Molecule of nitrogen (it contains 2 atoms).
H_2O	Molecule of water (2 atoms of hydrogen and 1 of oxygen).
NH_3	Molecule of ammonia (1 atom of nitrogen and 3 of hydrogen).
CuO	Molecule of black copper oxide.
Cu_2O	Molecule of brown copper oxide.
CO_2	Molecule of carbon dioxide ("di" means 2).
CO	Molecule of carbon monoxide ("mon" means 1).
$C_{12}H_{22}O_{11}$	Molecule of sugar (it contains 12 carbon atoms, 22 hydrogen atoms and 11 oxygen atoms.
H_2O_2	Molecule of hydrogen peroxide.

The system can be further extended to cover the number of molecules involved in a reaction.

2AgCl means 2 molecules of silver chloride, each containing 1 atom of silver and 1 atom of chlorine.

$4H_2SO_4$ means 4 molecules of sulphuric acid, each containing 2 atoms of hydrogen, 1 atom of sulphur and 4 atoms of oxygen.

CHEMICAL EQUATIONS

The idea can still be further extended to explain what happens in a chemical reaction. For example:

$$H_2+Cl_2=2HCl$$

means 1 molecule of hydrogen (containing 2 atoms) combines with 1 molecule of chlorine (containing 2 atoms) to form 2 molecules of hydrochloric acid gas each containing 1 atom of hydrogen and 1 of chlorine.

Note how the chemical equation is "balanced"—it cannot be an equation (both sides identical) unless it *does* balance.

H_2	$+$	Cl_2	$=$	2HCl
2 atoms of hydrogen		2 atoms of chlorine		2 atoms of hydrogen 2 atoms of chlorine

On page 202 is a list of the elements with their "code letters" or symbols and atomic weights.

(*a*) Note how in almost every case the letter or letters of the symbol give a clue to the name of the element.

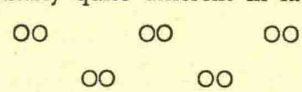
(*b*) No two codes are identical; e.g. since C stands for an atom of carbon, C cannot stand for an atom of copper, which becomes Cu (from the Latin word for copper, *cuprum*).

(*c*) In some cases the Latin name for an element has been used to fix its symbol; e.g. *aurum* is the Latin word for gold, and Au is the symbol for the atom of gold.

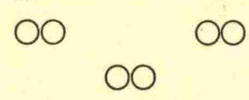
FORMULAE

Chemical formulae are really chemical recipes for the molecules of elements and compounds.

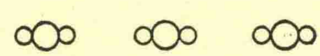
The molecules of hydrogen contain 2 atoms; they are written as H_2. If we think of the hydrogen atom as a tiny sphere of hydrogen we can imagine hydrogen molecules as something like this (though they are probably quite different in fact):



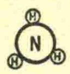
Oxygen molecules also contain 2 atoms (of oxygen this time, of course), so we write this down as O_2. We can imagine them looking somewhat like this:



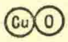
The molecules of water contain 2 atoms of hydrogen and 1 of oxygen. They are written as H_2O and could be thought of as:



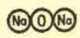
The formula for ammonia is NH_3, so we can visualise its molecules thus (to make things easier the atoms are "labelled" from now on):



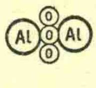
Black copper oxide is CuO. Its molecules might be like this:



Sodium oxide is Na_2O. Its molecules could be represented thus:



Aluminium oxide is Al_2O_3. Its atoms might be joined thus:



EQUIVALENT WEIGHTS

When an electric current is passed through water it is split up into hydrogen gas and oxygen gas; and these are collected separately. It is found that 8 gm. of oxygen are given off for every 1 gm. of hydrogen formed. Eight gm. of oxygen and 1 gm. of hydrogen explode when ignited and the result is water.

When the metal magnesium is dissolved in acid (*any* suitable acid) hydrogen gas is given off. If this is collected and weighed it is found that 12 gm. of magnesium has to be dissolved in order to liberate 1 gm. of hydrogen.

Magnesium burns violently in oxygen gas, and it is found that 12 gm. of magnesium combine with exactly 8 gm. of oxygen. (*Note.* We have already met this figure 8 gm. of oxygen!)

1 gm. of hydrogen combines with 35½ gm. of chlorine gas to form hydrochloric acid gas. Oddly enough, we find that it is exactly 35½ gm. of chlorine that is required to react with 12 gm. of magnesium to form magnesium chloride.

It appears, therefore, that hydrogen is involved in chemical reactions in "standard packets" of 1 gm., oxygen in standard packets of 8 gm., magnesium in standard packets of 12 gm., and chlorine in standard packets of 35½ gm.

And so we may go on, finding standard-weight packages for every element which enters into chemical action. These standard weights are given a special name—"*equivalent weights*".

The equivalent weight of an element is the number of grammes of the element that will combine with or displace 1 gm. of hydrogen. A more up-to-date (and therefore better) definition is "the number of grammes of the element that will combine with or displace 8 grammes of oxygen".

Note. Some elements have more than one equivalent weight. For example, copper in black copper oxide has an equivalent weight of 32, while in red copper oxide it has the equivalent weight of 64. We say that copper forms two distinct series of compounds, each with a different equivalent weight. To distinguish between them we call one the *cupric* compounds (equivalent weight is 32: cupric oxide is black copper oxide) and the other *cuprous* series (equivalent weight is 64: cuprous oxide is brown copper oxide).

Similarly, iron forms two distinct series of compounds: the ferrous compounds (equivalent weight = 28), and the ferric compounds (equivalent weight = 18⅔).

SOME COMMON FORMULAE

Formula	*Chemical Name*	*Common Name*
H_2O	Hydrogen monoxide.	Water.
HCl	Hydrochloric acid.	Spirits of salt.
H_2SO_4	Sulphuric acid.	Oil of vitriol.
HNO_3	Nitric acid.	Aqua fortis.
NaCl	Sodium chloride.	Common salt.
$NaNO_3$	Sodium nitrate.	Chile saltpetre.
$Na_2SO_4.10H_2O$	Sodium sulphate.	Glauber's salt.
$MgSO_4.7H_2O$	Magnesium sulphate.	Epsom salt.
$CuSO_4.5H_2O$	Copper sulphate.	Blue vitriol.
NaOH	Sodium hydroxide.	Caustic soda.
$Na_2CO_3.10H_2O$	Sodium carbonate.	Washing soda ("soda").
$NaHCO_3$	Sodium bicarbonate.	Baking soda ("carbonate of soda").
$CaCO_3$	Calcium carbonate.	Chalk.
$ZnCO_3$	Zinc carbonate.	Calamine.
$Na_2S_2O_3$	Sodium thiosulphate.	Photographer's "Hypo".

SOME COMMON EQUIVALENT WEIGHTS

Hydrogen	1	Copper	cupric	32
Oxygen	8		cuprous	64
Chlorine	35½	Iron	ferrous	28
Sodium	23		ferric	18⅔
Potassium	39	Silver		108
Magnesium	12	Calcium		20

VALENCY

There are various ways of finding out the formula of the molecules of a compound. There is no room here to deal with them in detail, but Gay Lussac's Law of Gaseous Volumes and Avogadro's Hypothesis are used in one method. Let us consider a few of these formulae.

(*a*) Hydrochloric Acid HCl
(*b*) Water H_2O
(*c*) Ammonia NH_3
(*d*) Methane (fire damp of the coal mines) CH_4

In (*a*), 1 *atom* of chlorine combines with 1 *atom* of hydrogen. We say chlorine has a valency of 1; or, in other words, chlorine is *monovalent.*

In (*b*), 1 *atom* of oxygen combines with 2 *atoms* of hydrogen. We say oxygen has a valency of 2; or, in other words, it is *bivalent* or *divalent* ("bi" and "di" both mean 2. Your *bi*cycle has two wheels—you *could* call it your *di*cycle for a change!)

In (*c*), 1 *atom* of nitrogen combines with 3 *atoms* of hydrogen. Nitrogen has a valency of 3; in other words, it is *trivalent.* (Tri means 3—remember the tricycle which you once rode!)

In (*d*), carbon clearly has a valency of 4.

The valency of an element is the number of hydrogen atoms with which one atom of the element will combine.

Valency is an indication of the *combining power* of an element—it comes from the Latin word *valere*, to be strong.

Incidentally, elements like copper and iron, which have two equivalent weights, also have two valencies—e.g. cupric compounds, valency 2; cuprous compounds, valency 1.

SOME COMMON VALENCIES

Hydrogen	1	Chlorine	1
Silver	1	Bromine	1
Cuprous (copper)	1	Iodine	1
Potassium	1	Oxygen	2
Cupric (copper)	2		
Zinc	2		
Magnesium	2		
Aluminium	3		
Ferrous (iron)	2		
Ferric (iron)	3		

Note. The arrangement in two separate columns above is deliberate, for it is found that elements in the left-hand column (hydrogen and the metals) do not combine with one another, but do combine with the elements (the non-metals) in the right-hand column. Similarly, the members of the right-hand column do not combine with each other, but do combine with the members of the left-hand column.

Using the Card Game to Work Out a Formula

Cut out a number of pieces of cardboard 1 in. square and on four of them write H in black ink, on another four Ag in black ink, on another four Cu "Cuprous" in black ink, on another four K in black ink, on another four Cl in *red* ink, and similarly four Br (red) and I (red). Each square represents an atom in a formula—black meaning metal (we include hydrogen here, though it seems odd to do so) and red meaning non-metal.

Now cut out cards 2″ × 1″ and prepare four with Zn in black, four more with Mg in black, and similarly four Cu "Cupric" and Fe "Ferrous". The cards for oxygen will also be 2″ × 1″, with O in red.

For Al and Fe "Ferric" we need cards 3″ × 1″, and writing in black.

Rules of the Game.

1. Two columns only to be used, black writing on the left and red on the right.
2. When a perfect rectangle has been built the compound can exist and its formula can be read off.
3. If the finished shape is not a rectangle, then the compound so built up will not exist.

Here are some examples:

HI—a proper formula.

H_2O—a proper formula.

(1 atom of valency 2 needs 2 atoms of valency 1 to satisfy it.)

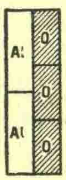
MgO—a proper formula.

$MgBr_2$—a proper formula.

$AlCl_3$—a proper formula.

(1 atom of valency 3 needs 3 atoms of valency 1 to satisfy it.)

Rule broken—not a rectangle; therefore not a proper formula.



Al_2O_3—a proper formula.

(2 atoms of valency 3 need 3 atoms of valency 2. $2 \times 3 = 6$; $3 \times 2 = 6$ also.)

Rule broken—black ink in right-hand column; therefore not a proper formula.

An Extension of the Game

A group of atoms NH_4 (the ammonium group) behaves exactly like a monovalent metal. Make some cards 1″ × 1″ for it and label them NH_4 in black.

A group of atoms NO_3 (the nitrate group) behaves just like a monovalent non-metal. Make some cards 1″×1″ and label them NO_4 in red.

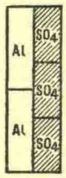
The group SO_4 (the sulphate group) behaves like a divalent non-metal, so write this in red on some 2″×1″ cards.

Here are a few additional proper "formulas"—formulae to use the correct plural of formula.

H_2SO_4 (sulphuric acid)

$Mg(NO_3)_2$ (magnesium nitrate)

$(NH_4)_2SO_4$ (ammonium sulphate, sulphate of ammonia — a good fertiliser)



$Al_2(SO_4)_3$ (aluminium sulphate)

THE WEIGHT OF AN ATOM

Since all things are made up of atoms, and all things have weight, it follows that the atoms themselves must have weight. What do they weigh? It has never been possible to take one atom on its own and weigh it, but there are methods of finding the weight of a known number of atoms—say a few million. Simple division will then give us the weight of an atom. That of the heaviest atom ever found in nature (uranium is about $\frac{1}{2,500,000,000,000,000,000,000}$ gm.

These tiny fractions are absolutely meaningless—nobody can imagine the size of such a tiny weight. It is just as awkward as a greengrocer putting up a notice that his blackcurrants are $£\frac{1}{300,000}$ each. We *could* deal with him, but would prefer to buy from another man who priced his blackcurrants in a way that meant something to us—e.g. at 10*d.* a lb. We do know what ten pennies look like!

The gramme is a pretty small weight itself—there are nearly 500 of them in a pound, and there is no smaller unit of weight in common use. The chemist therefore was bold and original—he broke away from all usual standards and invented his own particular unit.

The lightest element used to be the yardstick for all others. Hydrogen is an element that was discovered quite early, for it is given off as bubbles of gas whenever a strong acid is poured on metals like iron or zinc. It is also given off whenever an electric current is passed through water. If soap bubbles are blown with hydrogen gas instead of with breath they float out of sight with great speed. The gas is clearly much lighter than air. In fact, no lighter gas than hydrogen has ever been found, and no lighter atom than the atom of hydrogen has ever been discovered either. The chemist's special unit of weight was, then, *the weight of an atom of hydrogen*, and all other atoms had their weights compared with that of the hydrogen atom.

The atom of helium, a gas used for balloons and for the very few airships which are still in use, is four times as heavy as the atom of hydrogen. We say that the atomic weight of helium is 4.

The oxygen atom is sixteen times as heavy as the hydrogen atom; the atomic weight of oxygen is therefore 16. Chemists later decided to take as the standard one-sixteenth part of the weight of one atom of oxygen, instead of the weight of one atom of hydrogen.

The atomic weight of an element is the weight of the atom of that element divided by one-sixteenth part of the weight of an atom of oxygen.

Here are the atomic weights of the elements about which we have already spoken in this section. Just to gather facts together, let us put down, as well, their valencies and equivalent weights.

Element	*Atomic Weight*	*Valency*	*Equivalent Weight*
Aluminium	27	3	9
Bromine	80	1	80
Calcium	40	2	20
Carbon	12	4	3
Chlorine	35·5	1	35·5
Copper			
(Cuprous)	64	1	64
(Cupric)	64	2	32
Hydrogen	1	1	1
Iodine	127	1	127
Iron			
(Ferrous)	56	2	28
(Ferric)	56	3	18·7
Magnesium	24	2	12
Nitrogen	14	3	4·7
Oxygen	16	2	8
Potassium	39	1	39
Silver	108	1	108
Sodium	23	1	23
Zinc	65	2	32·5

A study of this table will bring to your notice a simple relationship—in every case *Atomic Weight = Equivalent × Valency.*

The weights of molecules. Molecules are built of individual atoms; and since each atom has weight, the molecule must have a weight equal to the total weight of the atoms in it. We are still in difficulties concerning a unit of weight, for molecules, like atoms, are far too light to be measured sensibly in pounds, ounces or grammes. The weight of a single *atom of hydrogen* has worked very well as the unit for atoms—we cannot do better than to use it again for molecules.

MOLECULAR WEIGHT

The molecular weight of an element or compound is the weight of its molecule divided by the weight of an atom of hydrogen.

(*Note.* It is the *atom* of hydrogen which is used as the standard—it is very easy indeed to quote a molecule of hydrogen in this definition—it sounds so much tidier! The more up-to-date unit is one-sixteenth of the

weight of an oxygen atom instead of the weight of one hydrogen atom.)

Let us work out a few molecular weights looking at page 202 for the atomic weights.

Hydrogen H_2 $H = 1.\ 2 \times 1 = 2$
The molecular weight of hydrogen is 2.

Oxygen O_2 $O = 16.\ 2 \times 16 = 32$
The molecular weight of oxygen is 32.

Nitrogen N_2 $N = 14.\ 2 \times 14 = 28$
The molecular weight of nitrogen is 28.

Water H_2O

$$\begin{array}{rr} H = 1. & 2 \times 1 = 2 \\ O = 16. & 1 \times 16 = 16 \\ \hline & 18 \end{array}$$

The molecular weight of water is 18.
(The molecular weight of steam, which chemically is the same as water, is also 18.)

Carbon Dioxide CO_2

$$\begin{array}{rr} C = 12. & 1 \times 12 = 12 \\ O = 16. & 2 \times 16 = 32 \\ \hline & 44 \end{array}$$

The molecular weight of carbon dioxide is 44.

Sugar $C_{12}H_{22}O_{11}$

$$\begin{array}{rr} C = 12. & 12 \times 12 = 144 \\ H = 1. & 22 \times 1 = 22 \\ O = 16. & 11 \times 16 = 176 \\ \hline & 342 \end{array}$$

The molecular weight of sugar is 342.

We have covered a great deal of ground already in this section, following in the footsteps of the clever scientists who by the middle of the nineteenth century had found a full explanation of how chemical changes came about. Let us summarise the ideas which were then held.

There were in the Universe millions of millions of tiny specks of matter called atoms. There were many different sorts of atoms, created as distinct varieties, and every one of these atoms must exist for all time. Man could, by his skill, break up existing groups of atoms and so get different groupings of atoms—i.e. he could persuade one chemical compound to change into another. Man also knew the weight of each kind of atom (on a special unit of weighing), so not only was he able to think out new chemical reactions, but he was able to work out the weights of the various chemicals which would be involved.

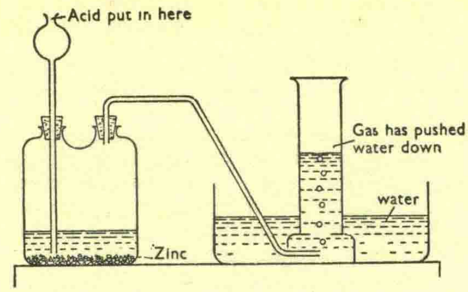
Let us give a few examples of such calculations using reactions which involve first hydrogen and then oxygen.

HYDROGEN

Hydrogen gas is generally prepared in the laboratory by acting on zinc with dilute sulphuric acid. Let us write down the formula of the substances involved.

$$Zn + H_2SO_4 \text{ gives } H_2 + ?$$

It has been found by experiment that after the zinc has dissolved, water may be driven off from the liquid left in the flask, leaving a white solid, zinc sulphate, $ZnSO_4$. It



is also known that the water in the dilute acid is not changed in the reaction.

We can thus write the statement:

$$Zn + H_2SO_4 \text{ gives } ZnSO_4 + H_2.$$

We are aiming at an *exact* statement, so let us examine it carefully.

On the left-hand side we find: 1 atom of zinc, 2 atoms of hydrogen, 1 atom of sulphur and 4 atoms of oxygen.

On the right-hand side we find: 1 atom of zinc, 1 atom of sulphur, 4 atoms of oxygen and 2 atoms of hydrogen.

These are the same: the statement is balanced, so it is an *equation.*

$$Zn + H_2SO_4 = ZnSO_4 + H_2$$

Let us put in the atomic and molecular weights.

$Zn + H_2SO_4 = ZnSO_4 + H_2$
$Zn = 65$
$H_2SO_4 = (2 \times 1) + 32 + (4 \times 16) = 98$
$ZnSO_4 = 65 + 32 + (4 \times 16) = 161$
$H_2 = (2 \times 1) = 2$

So 65 gm. of zinc dissolve in 98 gm. of sulphuric acid and produce 161 gm. of zinc sulphate and 2 gm. of hydrogen; or 65 lbs. of zinc dissolve in 98 lbs. of sulphuric acid and produce 161 lbs. of zinc sulphate and 2 lbs. of hydrogen; or 65 tons of zinc dissolve in 98 tons of sulphuric acid and produce 161 tons of zinc sulphate and 2 tons of hydrogen.

Note. It is all a matter of simple proportion.

Preparing hydrogen from sulphuric acid with zinc is convenient in the laboratory. It is far too expensive on a large scale when vast quantities are required for manufacturing processes.

Where electricity can be obtained cheaply from water power an electric current is passed through water, splitting it up into oxygen (a very useful substance too) and hydrogen.

Statement	H_2O gives $H_2 + O_2$
Check	2 hydrogen atoms and 1 oxygen atom do not balance 2 hydrogen atoms and 2 oxygen atoms (not balanced).
Another try	$2H_2O$ gives H_2 and O_2
Check	4H and 2O gives 2H and 2O (still not balanced).
Another try	$2H_2O$ gives $2H_2$ and O_2
Check	4H and 2O gives 4H and 2O (balances).
Equation	$2H_2O = 2H_2 + O_2$

Notes

(1) In making an equation balance, only the number of molecules may be adjusted—the structure of the molecules themselves is fixed. Clearly we cannot alter the nature of the substances we use by juggling with mathematics.

(2) The steps shown earlier in detail are usually mental and not written down. You will probably find yourself thinking like this:

"H_2O gives $H_2 + O$. But I cannot have a single O since oxygen molecules are O_2. So I'll have to double—$2H_2O$ gives $2H_2 + O_2$."

(3) When a chemical reaction is *known* to occur it may be illustrated with an equation. The converse is not true. You cannot necessarily make a chemical action occur merely because you have written down an equation to represent it.

$2H_2O = 2H_2 + O_2$ is a correct equation.

Molecular weights:

$$\begin{aligned} 2([2 \times 1] + 16) &= 2(2 \times 1) + (2 \times 16) \\ 2 \times 18 &= 2 \times 2 + 32 \\ 36 &= 4 + 32 \end{aligned}$$

36 tons of water when decomposed give 4 tons of hydrogen and 32 tons of oxygen.

Another way in which hydrogen is manufactured on the large scale is to blow steam (another form of water) over red-hot scrap iron. The substance left is magnetic iron oxide, a black mass with the formula Fe_3O_4. It is also known as smithy scales.

Statement	$Fe + H_2O$ gives $Fe_3O_4 + H_2$
Check	Obviously unbalanced.
Statement	$3Fe + H_2O$ gives $Fe_3O_4 + H_2$
Check	Iron balances—hydrogen and oxygen do not.
Statement	$3Fe + 4H_2O$ gives $Fe_3O_4 + H_2$
Check	Iron atoms balance, so do oxygen. Hydrogen needs looking at.
Statement	$3Fe + 4H_2O$ gives $Fe_3O_4 + 4H_2$ (balances)
Check	3Fe, 8H, 4O = 3Fe, 4O, 8H
Equation	$3Fe + 4H_2O = Fe_3O_4 + 4H_2$

Molecular weights:

$$\begin{aligned} 3 \times 56 + 4\,([2 \times 1] + 16) &= ([3 \times 56] + [4 \times 16]) + 4(2 \times 1) \\ 168 + 4 \times 18 &= (168 + 64) + (4 \times 2) \\ 168 + 72 &= 232 + 8 \end{aligned}$$

Therefore if 72 lbs. of steam combine with 168 lbs. of iron, the result is 232 lbs. of magnetic iron oxide and 8 lbs. of hydrogen. We can get something else from the equation, too: 4 molecules of steam produce 4 molecules of hydrogen gas.

But Avogadro's Hypothesis says that equal volumes of gas contain equal numbers of molecules (measured under the same conditions, of course, to be fair), so equal numbers of molecules must be in equal volumes of gases. Therefore 4 volumes of steam produce 4 volumes of hydrogen.

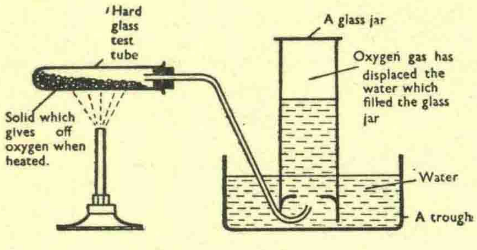
In other words, provided the steam and hydrogen have the same temperature, each volume of steam used will produce an equal volume of hydrogen.

OXYGEN

The traditional method of preparing a few jars of oxygen gas in the laboratory is by heating a substance, potassium chlorate, which is rich in oxygen and which has the formula $KClO_3$. The potassium chlorate is in the form of white crystals, and its oxygen is given off very reluctantly only when it is heated quite strongly. The

potassium chlorate melts and after the oxygen has gone another white solid is left behind—potassium chloride, KCl.

The apparatus normally used is:



Statement $KClO_3$ gives $KCl + O_2$
Check Obviously unbalanced.

Statement $2KClO_3$ gives $2KCl + 3O_2$
Check 2K, 2Cl, 6O = 2K, 2Cl, 6O
Equation $2KClO_3 = 2KCl + 3O_2$

This reaction is really dreadfully slow—is there not some way in which it can be speeded up?

The addition of a little manganese dioxide (a black powder, not to be confused with magnesium oxide) brings about an amazing change. Oxygen simply pours out of the potassium chlorate as it is gently warmed, and, most surprising of all, all the manganese dioxide is left unchanged at the end of the experiment. So to prepare oxygen gas in the laboratory we gently heat a mixture of potassium chlorate and manganese dioxide. We say that manganese dioxide has acted as a *catalyst*, or that it has had a *catalytic action*.

The equation can be written:

$$2KClO_3 + MnO_2 = 2KCl + 3O_2 + MnO_2$$

or

$$2KClO_3 = 2KCl + 3O_2$$

as only the substances actually changed in a chemical action need be included in the equation.

Oxygen is manufactured from liquid air. This is, in broad outline, a simple matter, though of course more complicated in the actual process designed for high efficiency. If you put your finger over the valve tube of a cycle tyre when you take out the valve, the rush of air feels cold. Better still, persuade your father to try the same experiment with the spare tyre of his car—there is more air there and you feel the effect more. It may be, of course, that we merely imagine the rush of air to be cold: we can check this with a thermometer, which shows conclusively that when compressed air is allowed to expand suddenly it cools itself down. (The converse is true, too, for when you compress air in your cycle pump you warm it up.)

Now imagine the cold air—obtained by allowing it to expand rapidly—being compressed again, cooled to take away the heat produced by compression, and then again allowed to expand suddenly. It gets colder still.

Now imagine this to take place dozens of times, the air getting steadily colder and colder. Finally it gets so cold that it forms a liquid—liquid air—just as the gas steam forms a liquid, water, when it is cooled down enough.

The liquid air is always on the boil, and as it is a mixture of liquids (liquid oxygen and liquid nitrogen) they boil off separately (Distillation—see page 193).

INTRODUCTIONS ARRANGED—THE WORK OF CATALYSTS

Many chemical actions take place very slowly, yet in the presence of another special substance they go ahead like wildfire. The odd thing, too, is that the extra substance put in to speed up the action is left unchanged at the end. It may be, of course, that it does take part in the action, but that it is again produced before the end. The explanation for one case of catalytic action may be quite different from that for others.

A catalyst is a substance which changes the speed of a chemical action without itself undergoing any lasting change. Most of the catalysts we use increase the speed of an action. There are some which slow it down: these are called negative catalysts.

There are several illustrations of a sort of catalytic action in everyday life. Have you ever been to a party which seems absolutely dead, with everybody keeping himself to himself until somebody, with a special gift of friendliness, arrives? From then on, everything goes with a swing, even though the person concerned may not even dance or join in the games. How about, too, the crowd of schoolboys in the cloakroom long after the end of school. They suddenly go into action and walk briskly out merely at the presence of a master. He does nothing—not even speak to them—yet his presence, for some queer reason, causes them to disappear!

To be honest, we should not be much worse off if manganese dioxide did not have this catalytic effect on potassium chlorate, for there are other, perhaps even better, methods of preparing small quantities of oxygen. There are, however, other catalytic actions which are extremely important to us and without which important chemicals would be much less plentiful and more expensive. Each particular case seems to need a different catalyst.

Sulphuric acid is one of the most important of manufactured chemicals. In its production we depend on a catalyst—finely divided vanadium pentoxide or metallic platinum—to persuade sulphur dioxide to combine with oxygen to produce sulphur trioxide.

Nitric acid is manufactured in vast quantities, the raw materials being the air and water. At one stage of the process ammonia gas has to combine with the oxygen of the air to form nitric acid, and this it will only do if passed through a gauze of platinum wire heated electrically—another useful catalyst.

Many vegetable oils have excellent food value, but are liquid at ordinary temperatures and not solid like butter. They are often "hardened" by heating them and treating them with hydrogen gas in the presence of finely divided nickel, which acts as the catalyst. The nickel is filtered off and the oil sets into a solid fat (margarine) on cooling.

Catalysts, too, are used in the petroleum industry, for with their aid heavy oils of little commercial use may be split up into petrol and gases which are useful in manufacturing other important products.

Nitrogen gas boils off and is collected (there is a sale for compressed nitrogen, in grey steel cylinders) and liquid oxygen is left. Sometimes it is sold as liquid oxygen—you may have seen the special insulated spheres on motor lorries, with their pipes covered with thick frost even on a hot summer day. Much of it is, however, allowed to evaporate so that the oxygen gas can be compressed in black steel cylinders and sold.

There is no equation here, for no chemical action has occurred. The molecules of nitrogen and oxygen, which have been separated, have not been combined but merely mixed.

CARBON

Carbon is an element which exists in several different forms—all pure carbon, but all quite different in appearance. A flawless diamond weighing an ounce would be almost beyond price. The chimney-sweep will be glad to give you a hundredweight of soot. Yet they are one and the same element. The diamond is the hardest substance known—it will scratch all other solids. The graphite in your pencil (it really isn't a "lead" pencil) is so soft that it is worn away by the soft paper on which you draw. Yet they are both carbon. We could clinch the matter in this way.

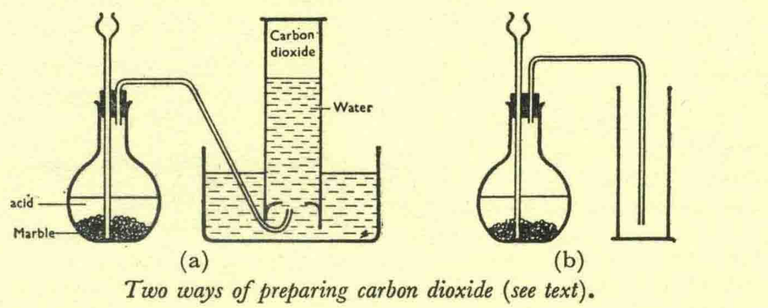
$$C + O_2 = CO_2$$
$$12 + (2 \times 16) = 12 + (2 \times 16)$$
$$12 + 32 = 44$$

12 gm. of any form of carbon when heated in oxygen burns away to form 44 gm. of carbon dioxide gas. This is in fact true for all the varieties mentioned, and for other forms which have not been mentioned. An element like this which exists in different forms is said to be *allotropic*.

CARBON DIOXIDE

This gas is usually prepared in the laboratory by acting on pieces of marble (calcium carbonate) with dilute hydrochloric acid.

It may be collected in either of two ways. Those who favour (*a*) (see diagram) admit that some of the carbon dioxide is lost, because it dissolves in water, but contend that what they do collect is all carbon dioxide



Two ways of preparing carbon dioxide (see text).

and not a mixture of it with air. They also say that they *know* when their jars are full of gas.

The supporters of (*b*) say it is unsound to collect over water a gas which dissolves in water, and, anyway, carbon dioxide is so much heavier than air that it is certain to stay in the bottom of the gas-jar and push out the lighter air.

Both ways work well, and the equation is:

$$CaCO_3 + 2HCl = CaCl_2 + H_2O_2 + CO_2$$

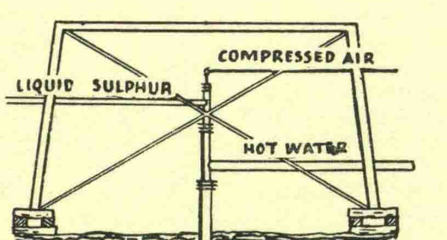
Carbon dioxide is used for many purposes. The "fizz" in ginger pop and soft drinks is carbon dioxide gas which has been dissolved in it; the froth on a glass of bottled beer is blown up by carbon dioxide; the ice-cream you buy from the van or tricycle in the street is kept cold and hard with solid carbon dioxide, and if you have a fire in your school laboratory the teacher will probably reach for a cylinder of liquid carbon dioxide to put it out.

How is it manufactured? One way is to ferment sugar solution with yeast. The result is carbon dioxide and another useful chemical, alchohol (C_2H_6O):

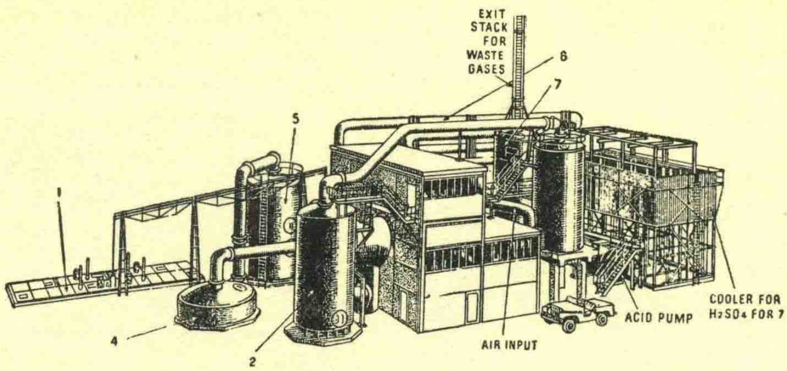
$$H_2O + C_{12}H_{22}O_{11} = 4C_2H_6O + 4CO_2$$

SULPHUR

Sulphur, which is often erupted by volcanoes, is found also in underground deposits resulting from volcanic activity of earlier ages. The chief ones are in Iceland, Italy, New Zealand, Japan, Mexico and in Texas and Louisiana in the U.S.A. Its low melting point (115°C.) enables it to be mined by pumping superheated water down a borehole, and using compressed air down an inner pipe to bring the melted sulphur to the surface; on cooling it solidifies into yellow crystals in giant vats (see below).



The greatest importance of sulphur is that sulphuric acid can be made from it (see diagram top right). Sulphur is melted (1) and then burned in air (2); of the resultant mixture of nitrogen (N_2), oxygen (O_2) and sulphur dioxide (SO_2), the latter two (SO_2 and O_2) are filtered out (4), and then mixed in the presence of the vanadium catalyst (5). The catalyst "persuades" SO_2 to add a further atom of oxygen (oxidisation) and become sulphur trioxide (SO_3).



The manufacture of sulphuric acid.

A good deal of heat is acquired during the reaction so the SO_3 is cooled (6) before the final stage. This cannot, as one would think, be the simple dissolving of SO_3 in water (H_2O), to give H_2SO_4 (sulphuric acid), for they only partially combine because the water tends to evaporate. So the SO_3 is bubbled through a tank of sulphuric acid previously manufactured (7) (absorber tower), and combines, easily producing strong H_2SO_4, which is then diluted with water to the usual strength used in numerous commercial processes. This is known as the contact (i.e. catalyst) process, and a number of other catalysts were used before the vanadium catalyst was developed, e.g. platinum, glass, porcelain. A less pure form of sulphuric acid can be made by the chamber process, in which sulphur dioxide is mixed with an oxide of nitrogen and steam, and cooled in lead chambers. Several salts produced by sulphuric acid are used as fertilisers for crops—e.g. ammonium sulphate, calcium superphosphate.

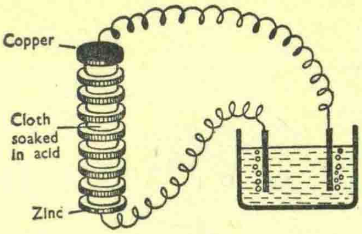
NEW IDEAS COME TO LIGHT

The simple picture of chemistry which we have so far described, in which atoms were regarded as solid little spheres of material, for ever unchangeable, has given way to new ideas in which the atoms themselves are built up of even tinier "standard parts"—the proton, the neutron and the electron (see page 186). There is now, in theory, nothing to prevent the alchemists' dream from being realised—of converting iron into gold; the only drawback is that it might cost a few million pounds to make a shillingsworth of gold! Nothing in the new theories conflicts with the main ideas of the earlier atomic theory—indeed, many things which we accepted and could not explain, like "valency", are now made clear. A monovalent metal, like sodium, we believe has a single electron in the "outer shell" of its atom, giving it a valency of 1. A divalent metal like calcium has, we understand, two such electrons in its outer shell, giving it a combining power or valency of 2. Aluminium will have three outer electrons—giving it its valency of 3, and so on. Chlorine, on the other hand, has room in its "outer shell" for just one more electron, so it is very willing to "make a deal" with sodium and pair up. The chlorine valency of 1 (due to the shortage of one electron) is different from the sodium valency of 1 (due to one odd electron). You will probably remember our using black and red ink in our card game, without really understanding why. Now you should know!

ELECTRICAL CHEMISTRY

Electricity may not, at first sight, seem to have a great deal to do with chemistry, but there is a very close connection indeed. The first electric current that was ever detected by man was due to a chemical action, and, oddly enough, it was registered quite accidentally by an instrument which we never use now—the legs of a dead frog. An Italian scientist, Luigi Galvani, noticed that the legs of a recently killed frog twitched when they touched both a copper hook and the iron rail on which they were to be hung. Galvani concluded that there was electricity, but wrongly thought that it came from the frog's legs. Alessandro Volta, another Italian scientist, confirmed that there was indeed electricity present but that it was caused by a chemical reaction between the copper, the iron and the fluid of the legs. The muscles of the dead frog *detected* the electricity—they did not *produce* it. Volta soon showed that he could obtain really powerful electrical effects like electric shocks from pieces of copper, pieces of zinc and a solution of either common salt or of acid. *When chemical actions occur, therefore, one of the effects can be the setting up of an electric current.* By the way, Galvani and Volta worked about 1800—the period in which so many exciting chemical ideas were being put forward.

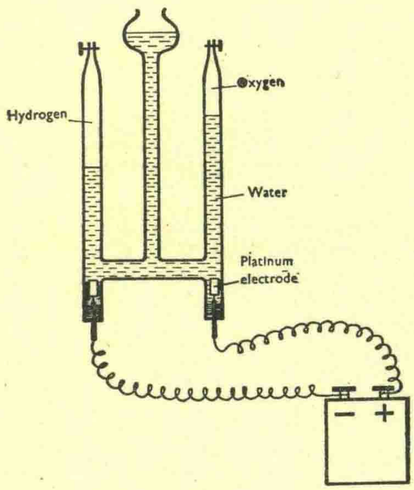
Volta's pile of copper and zinc discs, in this order—copper, cloth, zinc, copper, cloth, zinc, copper, cloth, zinc, copper, cloth, zinc and so on—had a wire connected to the copper disc at one end and another to the zinc disc at the other end. As soon as the cloth was soaked in acid an electric battery was at work. Chemical energy was used up as the zinc dissolved in the acid, and electrical energy was made available.



The very first experiment on the electrolysis of water: Carlisle and Nicholson, in England, were thoughtful enough (in 1800) *to collect the bubbles and to identify the gases.*

Note. In both cases a chemical action is the *cause* of the electricity (in the Volta pile and in the 6-volt car battery). In both cases, too, chemical action (the decomposition of water into hydrogen and oxygen) is the *result* of the electricity. Surely nobody can now doubt the fact that chemistry and electricity are closely related sciences.

The splitting up of a compound by electrical means is called *electrolysis.* In the electrolysis of water the volume of hydrogen is exactly twice that of the oxygen.



A modern experiment in the electrolysis of water.

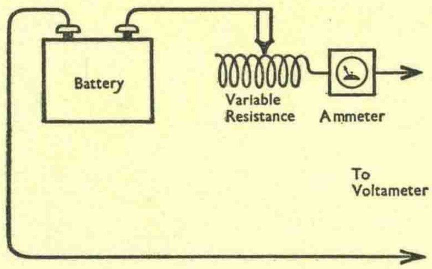
1. *The effect of time on the volumes of gas formed.* Notice the volume of hydrogen formed in 5 minutes, 10 minutes, and 20 minutes. The volume each time is double the previous recording—i.e. double the time, double the volume of gas produced.

The quantity of a substance formed in electrolysis is directly proportional to the time during which the current flows.

2. *The effect of the size of the current on the volume of hydrogen produced.* This time one experiment is carried out with a certain current, say $\frac{1}{10}$ ampere, for 15 minutes, and the volume of hydrogen formed is noted. A second experiment, also for 15 minutes, is carried out with a current of $\frac{2}{10}$ ampere—twice as much hydrogen is produced. A third 15-minute experiment with $\frac{3}{10}$ ampere gives three times the volume of hydrogen, and so on.

The quantity of substance formed is directly proportional to the current which is passed through the solution.

The current is measured on the dial of a meter—called an ammeter. It can be regulated by altering the resistance of the circuit by moving a slider along a coil of high-resistance wire so as to include more or less of this in the circuit (see below).



3. *The effect of the nature of the substance deposited.* Always two volumes of hydrogen are released for every one volume of oxygen. Oxygen gas is 16 times as dense as hydrogen, so 1 volume of oxygen weighs 8 times as much as 2 volumes of hydrogen. Thus when 1 gm. of hydrogen is released, 8 gm. of oxygen are also given off.

Concentrated hydrochloric acid can also be split up by electrolysis, and in this case equal volumes of hydrogen and chlorine are liberated. Now chlorine gas is 35·5 times as heavy, volume for volume, as hydrogen, so it follows that 35·5 gm. of chlorine are liberated while 1 gm. of hydrogen is given off.

Have you noticed that 1 gm. of hydrogen, 8 gm. of oxygen and 35·5 gm. of chlorine are all equivalent weights?

The weight of an element deposited in electrolysis is proportional to its equivalent weight.

THE ATOMIC WEIGHTS OF THE ELEMENTS

Because Oxygen, unlike Hydrogen, combines so easily with most other elements (it is easier to find the equivalent weights for Oxygen for each element), the exact Atomic Weights have been worked out on the basis of Oxygen = 16. Hydrogen then becomes, not exactly 1, but 1.008 and the other elements vary accordingly. For most purposes it is quite all right to use the round numbers as in some recipes in this article.

Element	*Symbol*	*At. Wt.*
Hydrogen	H	1.01
Helium	He	4
Lithium	Li	6.94
Beryllium	Be	9.01
Boron	B	10.82
Carbon	C	12.01
Nitrogen	N	14.01
Oxygen	O	16.00
Fluorine	F	19.00
Neon	Ne	20.18
Sodium	Na	23
Magnesium	Mg	24.32
Aluminium	Al	26.97
Silicon	Si	28.06
Phosphorus	P	30.98
Sulphur	S	32.07
Chlorine	Cl	35.46
Potassium	K	39.11
Argon	A	39.94
Calcium	Ca	40.08
Scandium	Sc	45.10
Titanium	Ti	47.90
Vanadium	V	50.95
Chromium	Cr	52.01
Manganese	Mn	54.93
Iron	Fe	55.85
Nickel	Ni	58.69
Cobalt	Co	58.94
Copper	Cu	63.67
Zinc	Zn	65.38
Gallium	Ga	69.72
Germanium	Ge	72.60
Arsenic	As	74.91
Selenium	Se	78.96
Bromine	Br	79.92
Krypton	Kr	83.7
Rubidium	Rb	85.48
Strontium	Sr	87.63
Yttrium	Y	88.92
Zirconium	Zr	91.22
Niobium	Nb	92.91
Molybdenum	Mo	95.95
Masurium	Ma	99
Ruthenium	Ru	101.7
Rhodium	Rh	102.91
Palladium	Pa	106.7
Silver	Ag	107.88
Cadmium	Cd	112.41
Indium	In	114.76
Tin	Sn	118.70
Antimony	Sb	121.76
Iodine	I	126.92
Tellurium	Te	127.61
Xenon	Xe	131.3
Caesium	Cs	132.91
Barium	Ba	137.36
Lanthanum	La	138.92
Cerium	Ce	140.13
Praseodymium	Pr	140.92
Neodymium	Nd	144.27
Promethium	Pm	147
Samarium	Sm	150.43
Europium	Eu	152.0
Gadolinium	Gd	156.9
Terbium	Tb	159.2
Dysprosium	Dy	162.46
Holmium	Ho	164.94
Erbium	Er	167.2
Thulium	Tm	169.4
Ytterbium	Yb	173.04
Lutecium	Lu	174.99
Hafnium	Hf	178.6
Tantalum	Ta	180.88
Tungsten	W	183.92
Rhenium	Re	186.31
Osmium	Os	190.2
Iridium	Ir	193.1
Platinum	Pt	195.23
Gold	Au	197.2
Mercury	Hg	200.61
Thallium	Tl	204.39
Lead	Pb	207.21
Bismuth	Bi	209.00
Polonium	Po	210
Astatine	At	210
Radon	Rn	222
Francium	Fr	223
Radium	Ra	226.05
Actinium	Ac	227
Protoactinium	Pa	231
Thorium	Th	232.12
Neptunium	Np	237
Uranium	U	238.07
Plutonium	Pu	239
Americium	Am	241
Curium	Cm	242
Berkelium	Bk	243
Californium	Cf	244
Einsteinium	E	247
Nobelium 5	No	253
Fermium	Fm	255
Mendelevium	Mv	256

FARADAY'S LAWS OF ELECTROLYSIS

1. The weight of an element deposited in electrolysis is proportional to the quantity of electricity passed through the solution—i.e. to the strength of the current and to the time for which it flows.

2. The weight of an element deposited is proportional to its equivalent weight.

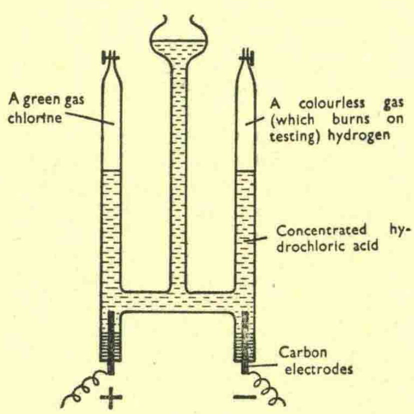
Note. In electrolysis 96,500 coulombs of electricity (a coulomb is 1 ampere flowing for 1 second) will liberate the equivalent weight of any element—e.g. 1 gm. of hydrogen, 8 gm. of oxygen, or 108 gm. of silver.

The metal connection in an electrolysis is known as an electrode. The most suitable metal is the very expensive element platinum, for it is not easily corroded. The electrode connected to the positive terminal of a battery is the *positive electrode* or *anode*; that connected to the negative terminal of the battery is the *negative electrode* or *cathode*.

1. *The electrolysis of water.* Pure water has quite a high electrical resistance, so to bring about a reasonable rate of decomposition the resistance is lowered by adding a few drops of sulphuric acid. (The volume of sulphuric acid added does not affect the result.) The electrolysis of water is, in fact, the same as the electrolysis of dilute sulphuric acid. The reason for this is explained later. The result is 2 volumes of hydrogen at the negative electrode and 1 volume of oxygen at the positive electrode.

$$2H_2O = 2H_2 + O_2$$

2. *The electrolysis of concentrated hydrochloric acid.* Experience has shown that during this experiment the platinum electrodes *are* corroded and dissolve, although hydrochloric acid itself does not attack platinum. We cannot afford to lose valuable platinum, so for this experiment we use carbon rods instead. Those taken from small dry cells are very suitable.

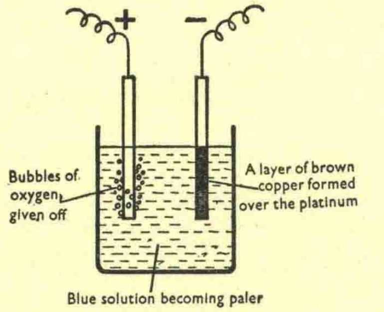


Note. For a very long time after the start of the experiment the bubbles of gas given off at the positive electrode disappear as they pass upward through the acid—they dissolve in it. Finally, however, they do reach the top, for the acid becomes saturated and can dissolve no more gas. It is at this point that all the gases already collected are allowed to escape through the taps at the top and a fresh start made.

Result: 1 volume of hydrogen over the negative electrode.
1 volume of chlorine over the positive electrode.

$$2HCl = H_2 + Cl_2$$

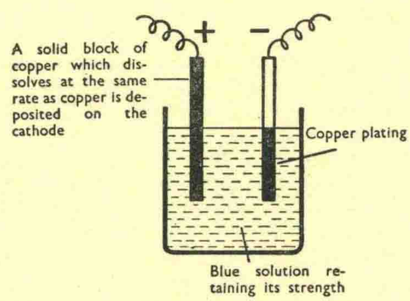
3. *The electrolysis of copper sulphate solution, with platinum electrodes.* The strength of the copper sulphate solution (which is bright blue) is not important.



This is an example of "copper plating". The blue solution becomes paler as it loses copper (which is deposited on the negative plate).

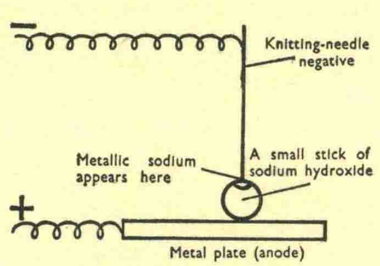
$$2CuSO_4 + 2H_2O = 2Cu + 2H_2SO_4 + O_2$$

4. *The electrolysis of copper sulphate solution with a copper anode (positive plate).* This is a better example of copper plating. Copper is dissolved from the anode and deposited upon the cathode (usually the article to be plated), so long as the current is passing. No gases are given off.



5. *The electrolysis of "solid" sodium hydroxide.*

Note. Sodium hydroxide must not be handled with the fingers—it decomposes skin! This experiment should only be performed by an experienced science teacher, with a sheet of glass between the experiment and those watching it.



For the first few seconds no current passes, for solid sodium hydroxide does not conduct electricity. It attracts moisture from the air, however, and a solution which does conduct electricity soon forms on the surface. The current melts a little pool of sodium hydroxide around the needle point and in this a bead of molten sodium (silvery metal) is formed.

Ionisation—an explanation of electrolysis

1. The molecule of water is H_2O. Let us write it HOH. We believe that some of the water molecules split up into H and OH and that each part of the molecule has an electric charge, equal in quantity but opposite in sign—i.e. one will be positive and the other negative.

$$HOH = \left\{ \begin{array}{l} \text{H charged} \\ \text{and} \\ \text{OH charged, equally but} \\ \quad\text{opposite} \end{array} \right.$$

How can we tell which is positive? It is a well-established principle that similar electric charges *repel* each other (positive repels positive and negative repels negative) and that opposite charges *attract* (+ attracts − and − attracts +).

Hydrogen gas in electrolysis always appears at the *negative electrode*, and whatever is attracted to the negative plate must be positive.

$$\text{So } HOH = H^{\text{positive}} + OH^{\text{negative}}$$

The hydrogen atom with a positive charge is called a hydrogen ion and is written H^+. The OH group (the hydroxyl group), with an equal negative charge, is called a hydroxyl ion, and written OH^-.

So in water there are always a number of H^+ and OH^- mixed with ordinary water molecules (H_2O). When a current is passed through the water, the hydrogen ions (H^+) are attracted to the negative plate and the hydrogen ions (OH^-) are attracted to the positive plate. At the negative plate the positive charges of the H^+ are neutralised by the negative charge of the plate, so the hydrogen ion is transformed into an ordinary hydrogen atom. This at once finds a partner to form a molecule of hydrogen (H_2) which comes off as gas.

At the positive electrode, hydroxyl ions have their negative charges neutralised and become OH groups. Four of these get together to form two molecules of water and one of oxygen, which escapes as bubbles.

To summarise:

$$\left.\begin{array}{l} H_2O \\ H_2O \\ H_2O \\ H_2O \end{array}\right\} \begin{array}{c} \\ \text{ionise} \\ \rightarrow \\ \\ \end{array} \begin{array}{l} H^+ \\ H^+ \\ H^+ \\ H^+ \end{array} \qquad \begin{array}{l} OH- \\ OH- \\ OH- \\ OH- \end{array}$$

negative pole | *positive pole*

$$2H_2 \leftarrow \left\{ \begin{array}{l} H \\ H \\ H \\ H \end{array} \right. \qquad \left. \begin{array}{l} OH \\ OH \\ OH \\ OH \end{array} \right\} \rightarrow 2\,H_2O + O_2$$

i.e. $4H_2O = 2H_2O + 2H_2 + O_2$.

The effect of adding dilute sulphuric acid (which itself ionises) is to introduce many more ions which help the liquid to conduct electricity. The effect is the same as with water, since hydroxyl ions are neutralised at the positive electrode in preference to sulphate ions, which remain in solution.

2. *Hydrochloric acid.* When hydrochloric acid gas dissolves in water, some of it splits up into ions:

$$HCl \qquad H^+ \qquad Cl^-$$

so concentrated hydrochloric acid contains HCl molecules, hydrogen ions and chlorine ions all mixed up.

The current directs the ions, H^+ going to the negative carbon and Cl^- to the positive carbon.

The charges are then neutralised.

At the positive electrode Cl^- becomes Cl and two chlorine atoms form a molecule of chlorine, $2Cl = Cl_2$, so chlorine gas is given off.

At the negative electrode H^+ becomes H and $2H = H_2$, and hydrogen gas is given off.

3. *Copper sulphate solution with platinum electrodes.* Copper sulphate, when dissolved in water, forms positive copper ions and negative sulphate ions.

$$CuSO_4 = Cu^{++} \quad SO_4^{--}$$

Note. The number of charges is the same as the valency (see earlier in this section). Also some of the water forms ions

$$HOH = H^+ \text{ and } OH^-$$

So in the blue copper sulphate solution we have, all mixed up, molecules of water (H_2O), molecules of copper sulphate ($CuSO_4$), ions of copper (Cu^{++}), ions of hydrogen (H^+), sulphate ions (SO_4^{--}) and hydroxyl ions (OH^-). When the current passes, the Cu^{++} and the H^+ go to the negative electrode, where under these conditions Cu^{++} becomes Cu and H^+ stays unchanged. So copper is formed on the negative electrode.

Also, as the current flows, the sulphate ions (SO_4^{--}) and the hydroxyl ions (OH^-) collect around the positive electrode. Under the conditions of this experiment the hydroxyl ions are discharged and the sulphate ions are unchanged, staying in solution.

$$OH^- \rightarrow OH$$

$$2OH = H_2O + O. \quad 2O = O_2$$

Oxygen atoms are liberated, form molecules and are given off as oxygen gas.

4. *Copper sulphate with a copper anode.* Copper ions (Cu^{++}), hydrogen ions (H^+), sulphate ions (SO_4^{--}) and hydroxyl ions (OH^-) form as before and are directed to the electrodes by the current.

At the anode. Under the changed conditions it is easier for copper to go into solution and form more copper than it is for the hydroxyl or sulphate ions to be discharged. At the cathode, copper is deposited as before and hydrogen ions remain in solution.

5. *Solid sodium hydroxide.*

Ionisation: $NaOH = Na^+$ and OH^-, $H_2O = H^+$ and OH^- — as soon as it is damp.

At negative (knitting needle) Na^+ neutralised and becomes Na. Sodium metal formed. H^+ neutralised and becomes $2H = H_2$.

At positive (metal plate) OH^- neutralised and becomes OH. $2OH = H_2O + O$. $2O = O_2$. Therefore oxygen given off.

ELECTROLYSIS IN INDUSTRY

1. Electrolysis of water to give both hydrogen and oxygen.
2. Purification of crude copper by making it the anode in a bath of copper sulphate solution, and causing pure copper to deposit on a thin plate of pure copper which is made the cathode.
3. Copper-plating of iron and steel to make it rust-proof—often the first stage in chromium-plating.
4. Nickel-plating, to give a bright silvery surface to brass or copper. Nickel coatings are very tough and continuous but tend to go cloudy unless cleaned regularly.
5. Chromium-plating, the standard bright finish for cycle and motor-car parts. Pleasant in appearance and needing little cleaning, but inclined to have "pin holes" exposing metal beneath. Hence the desirability of copper-plating followed by nickel-plating followed by chromium-plating. Each skin need be only a few thousandths of an inch thick.
6. Cadmium-plating for rust prevention in radio and television sets.
7. Extraction of sodium, by a method similar to that described but on a large scale.
8. Extraction of aluminium from its ores. Until the electrolysis method was introduced aluminium was a comparatively expensive and little-known metal. Now it is produced cheaply and in immense quantities (see page 189).

CHEMICALLY MADE ELECTRICITY

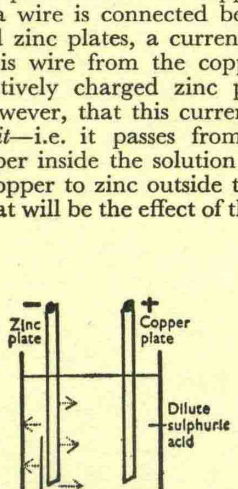
The theory of "ionisation"—the splitting up of certain compounds called acids, bases and salts into electrically charged "ions"—explains very satisfactorily the chemical changes which result from the passage of an electric current through such compounds. Could it perhaps be used also to explain the discovery of Volta, that a chemical action can produce an electric current?

Let us consider the possibility. In electrolysis, electrical energy brings about chemical changes: is it not possible that in an electric cell chemical changes might release electrical energy? In electrolysis the effect of the electric current is to direct the ions which are straying about in the solution *to* the metal plates; when zinc dissolves in acid might it not be giving out zinc ions which stray away *from* the plate of zinc? Opposite effects might easily be the result of opposite causes. We do, in fact, believe that they are, and we can explain the action of electric cells on the theory of *Ions*.

Let us take the simplest possible cell as an example: a plate of zinc and a plate of copper in dilute sulphuric acid. Zinc dissolves in dilute sulphuric acid, copper does not.

When the zinc dissolves, zinc ions (i.e. zinc atoms with two positive charges of electricity) leave the zinc plate and wander off into the solution. For a start, the zinc plate was neutral (i.e. it had just as many positive as negative charges), so the effect of the zinc ions going away with positive charges will result in fewer positive charges on the zinc (i.e. it will show a negative charge compared with the copper plate). So, when a wire is connected between the copper and zinc plates, a current will flow through this wire from the copper to the more negatively charged zinc plate. We believe, however, that this current *completes a full circuit*—i.e. it passes from the zinc to the copper inside the solution as well as from the copper to zinc outside the cell.

Now what will be the effect of this current passing *through the solution*? *Electrolysis*, of course.



Now we have present hydrogen ions and hydroxyl ions from the water ($H_2O = H^+ + OH^-$), hydrogen ions and sulphate ions from the sulphuric acid itself ($H_2SO_4 = H^+ + H^+ + SO_4^{--}$) and zinc ions from the zinc plate. The zinc and hydrogen ions (positive) are carried by the current to the copper plate (where the current leaves the solution). Under these conditions hydrogen ions are neutralised most readily, leaving zinc ions in solution. $H^+ \rightarrow H$. $2H = H_2$: and hydrogen gas is given off around the copper.

Negatively charged sulphate ions and hydroxyl ions go "against the current" to the zinc. Under the conditions of the experiment it is easier for metallic zinc to form positive ions and go into the solution than it is for either the sulphate or the hydroxyl ions to be discharged. So as electrical energy is produced, the zinc plate is dissolved.

This account, complicated though it may seem at first reading, is not the whole story, but it is true as far as it goes and does explain the essential working of the cell.

POSITIVE AND NEGATIVE

We have already mentioned the component parts of the atom—positively charged protons, neutral neutrons and negatively charged electrons. The protons and neutrons are tucked away comfortably in a tightly packed central core or "nucleus". The electrons are believed to whiz around this in an orderly fashion, and it is, in fact, the number and arrangement of these electrons which determine the chemical behaviour of an element (whether it is a metal or a non-metal, for example) and its valency. You can always find out how many electrons an atom has "milling" around it by looking up its Atomic Number. An atom of hydrogen has 1—Atomic Number 1. An atom of uranium has 92—Atomic Number 92.

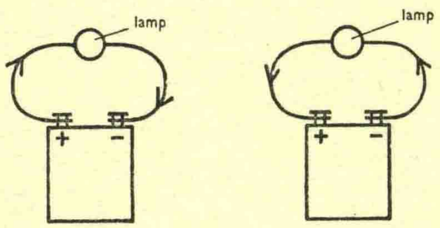
A *hydrogen ion* is believed to be an atom of hydrogen which has lost an electron—i.e. it has one negative charge short. It is *less negative* than the atom so is said to be *positively charged.*

A chlorine atom has 17 electrons—a *chlorine ion* has 18 electrons (i.e. one negative electron more than the atom), so it has a *negative charge* compared with the chlorine atom.

When an electric current flows it is believed to be the passing of electrons from one atom to the next atom, and so on. So when you switch on your electric torch

you complete a path which allows every atom in the chain to receive electrons from its neighbour on one side and then to part with an equal number of its own electrons to its neighbour on the other side; and this goes on, round and round the whole chain of atoms, at lightning speed until either the chain is broken (by switching off) or the driving force (the chemical action in the battery) is exhausted. Copper is a good conductor because it readily accepts extra electrons from neighbouring copper atoms and immediately passes on an equal number of its own.

We have always said so far that a current of electricity passes from the positive terminal of a battery through the connecting wire and lamp to the negative terminal. We now believe that a current of electrons flows from the negative terminal through the wire to the positive terminal.



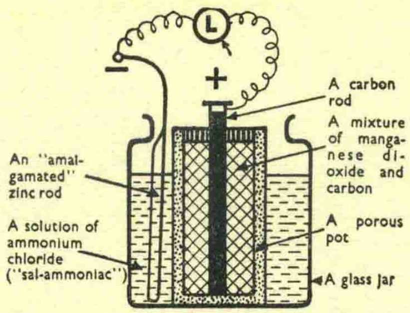
What a mess we seem to have got into! It might be best to have a clean start and to pass a law to the effect that "after a certain date currents will flow from the negative to the positive and not as previously stated". But, would all countries fall in line, and would we find it easy to forget the practice of the past century and a half? No, we try to make the best of both worlds. In his everyday life the scientist thinks readily of electric currents flowing from positive to negative, i.e. from the copper plate, through a connecting wire to the zinc plate. When, however, he is seeking to explain *how* something happens he turns to his electrons and remembers that they do, in fact, move in the reverse way.

After all, a positive current going one way isn't very different from a negative current going the other way.

It is, of course, a great pity that the early electricians did not say that the current moved from the zinc to the copper—they could well have done so and we should have none of the present confusion. But they were guided by even earlier experimenters who said, unfortunately (and for no particular reason), that the electricity ("static" electricity we call it) obtained by rubbing glass with silk was *positive,* and that obtained by rubbing sealing-wax with cats' fur was *negative.* We should fight down the temptation to blame them, for what they said with their existing knowledge was sound enough. We should, however, remember, whenever in doubt, to get down to first principles and think out what the electrons do.

THE SIMPLE CELL

The simple cell suffers from two serious faults. The zinc dissolves in the dilute sulphuric acid continuously (even when the cell is not being used). This is wasteful: the name of this fault is *Local Action.* It



The Leclanché cell is a much improved version of a simple cell.

is cured in the Leclanché cell by using a less active liquid, ammonium chloride solution instead of dilute sulphuric acid, and by coating the surface of the zinc with mercury to "amalgamate" it.

The second fault is noticed immediately hydrogen gas is given off at the positive (copper or carbon in this case). The current drops off at once. This fault is called *Polarisation.* It is believed to have two causes—the high resistance to the electric current of hydrogen which forms a coating on the positive plate, and the fact that the hydrogen and copper (or carbon) form a little electric cell of their own which opposes the main cell. The cure is to remove hydrogen as soon as it is formed. The manganese dioxide is rich in oxygen and converts hydrogen to harmless water. Carbon is mixed with the manganese dioxide to help it conduct the electric current.

The explanation for these faults is as follows. The ammonium chloride forms ammonium ions (NH_4^+) and chloride ions (Cl^-). Zinc ions (Zn^{++}) leave the zinc plate and go into the solution, thus leaving the zinc plate with electrons to spare. These electrons pass from the zinc to the carbon through the lamp (the external circuit), and as a result the ammonium ions pass through the solution to the carbon, when they receive electrons (one electron each ion) and become NH_4 (a substance which does not exist on its own).

$$2NH_4 = 2NH_3 \text{ (ammonia)} + H_2$$

Hydrogen gas is given off but reacts at once with manganese dioxide (MnO_2) to form another oxide of manganese, less rich in oxygen (Mn_2O_3).

$$2MnO_2 + H_2 = Mn_2O_3 + H_2O$$

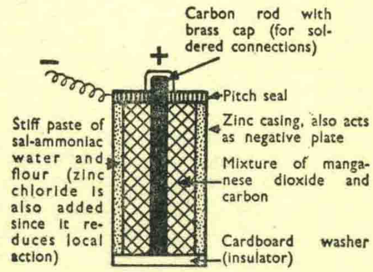
More zinc ions go into solution from the zinc plate. The chloride ions are not discharged, but remain in solution. The overall chemical equation is:

$$Zn + 2NH_4Cl + 2MnO_2 = ZnCl_2 + 2NH_3 + Mn_2O_3 + H_2O.$$

The Leclanché cell is best suited to a lazy and leisurely life. The manganese dioxide is rather a slow oxidiser, and if a large current of electricity causes a rapid gathering of hydrogen around the carbon the manganese dioxide is not able to cope with it quickly enough. After an hour's rest, however, all is well again, for the manganese dioxide will have had time to "digest" its too rapid meal of hydrogen gas and change it all to water. Leclanché cells can be set up for use in bell circuits, and left for years without any attention.

THE DRY CELL

This is an ingenious adaptation of the Leclanché cell. A better name would be the "Damp Cell", for if it really is dry it will not work (for ions only appear in solution or in molten material).



A REVERSIBLE CELL

In theory, we might pass a current through a Leclanché cell in the opposite direction to that in which the current produced by the cell flows, and reverse the chemical action which has occurred. That is, we might persuade the zinc which has dissolved to be plated on the zinc rod, the Mn_2O_3 to be changed to MnO_2, the ammonia to return to ammonium chloride, and so on. In practice we don't really succeed, for the recharged Leclanché cell is much below the standard which it achieved previously. The chemical reactions in the Leclanché cell are therefore not satisfactorily reversible.

There are cells, however, in which satisfactory reverse reactions are possible, and these are called "*secondary cells*" in contrast with the "primary cells" such as the simple cell and the Leclanché cell. The car accumulator is usually a collection of six secondary cells, each of two volts, making a battery of twelve volts all told. When the car starter switch is pressed, the chemical reaction goes one way and, as a result, chemical energy is used up and electrical energy produced. As soon as the engine has started, the dynamo passes an electric current (in the reverse direction) through the battery, and, as a result of this, the reverse chemical action occurs and the original chemicals are restored.

The "positive plate" of a lead accumulator is packed with a brown substance, lead peroxide (PbO_2). The "negative plate" is packed with a special porous form of metallic lead, light grey in colour (Pb). The liquid (electrolyte) is a mixture of sulphuric acid and water (dilute sulphuric acid). When the starter motor is connected between the positive and negative plates, and the switch is closed, electrons flow from the lead plate through the switch and through the starter to the lead peroxide. As previously explained, the electron flow must go round full circle—i.e. pass through the sulphuric acid from the lead peroxide to the lead. The final result of this is:

(1) lead peroxide changed to lead sulphate (white);
(2) lead changed to lead sulphate;
(3) some sulphuric acid changed to water.

The real cause of the excess of electrons on the lead plate is that in lead peroxide the lead has an unusual, inflated valency of 4, whereas the lead itself in the negative

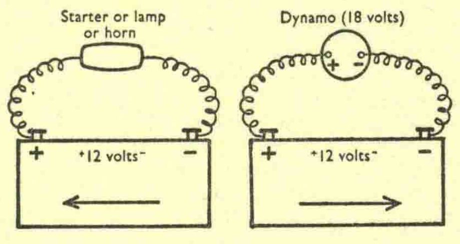
plate has a normal valency of 2. Thus in the positive plate we have lead with valency 4, and in the negative, lead with valency 2.

Note. In H_2O there is 1 oxygen atom to 2 hydrogen atoms. $\therefore$ oxygen has valency of 2.

In PbO_2 there is 1 atom of lead to 2 atoms of oxygen, each of valency 2. $\therefore$ Valency of lead in lead peroxide $= 2 \times 2 = 4$.

A valency of 4 on the positive plate is associated with 4 charges. A valency of 2 on the negative plate is associated with 2 charges. So once the two plates are connected, the excess of 2 positive charges (for each molecule of PbO_2) on the positive plate is able to attract 2 negative electrons from the negative, and so the electric current starts. The current can continue to flow until the difference in charge between the plates has been finally put right—when they are both exactly alike in the form of lead sulphate. Then the battery is run down, or "flat".

There is no need, however, to throw it away and to buy another. (It is just as well, for one by a well-known maker costs at least £10.) A steady current passed through the accumulator for a few hours will produce the original chemicals ready for a fresh spell of duty. Notice, however, that the direction of the current through the cell must be in the reverse direction while charging.



In use. Direction of electric current.　　*Charging.* Direction of electric current.

Remember that the electrons actually move in the opposite direction to the so-called electric currents.

ANALYSIS

One of the important aspects of a chemist's work is the splitting up of a complex substance or a mixture of substances to decide what it contains. This process is called "*Analysis*". Sometimes the chemist is content to know the names of the substances only—this is "*Qualitative Analysis*". Sometimes he has to go further and find the quantity present—this is "*Quantitative Analysis*".

Analysis can never be just a "hit or miss" effort—patient systematic work is necessary. There are well-known schemes of qualitative analysis, the result of much previous experience, which remind one of the way in which goods trucks are sorted, isolated and recognised in the sidings of a railway marshalling yard. The following scheme of analysis, by means of which the twenty-two most common metals may be identified in mixtures of their compounds, has been set out in this style as an illustration (although, of course, in a real chemical analysis railway points, sidings and buffers would not be thought of!).

Although this system of analysis is a little cumbersome and is unpleasantly smelly in places, it is generally preferred to methods more recently introduced, largely because there is a great deal of very important chemistry to be learned from its use. The scheme only holds good if a start is made at the beginning, e.g. metals which should have been "shunted off" at junctions I and II will cause wrong results if present for later tests.

Lead appears twice because its chloride is fairly insoluble in water. Enough remains undissolved to bring lead into the first group, yet sufficient does dissolve to get past junction I and so affect group II.

At junction I, lead, silver and mercurous salts are "shunted off" because their chlorides are insoluble in cold water. At A, lead is diverted because its chloride dissolves in hot water. At B, silver is "shunted off" because its chloride dissolves in ammonium hydroxide solution.

At junction II, mercuric, lead, bismuth, copper, cadmium, arsenic, tin and antimony salts are shunted off because their sulphides are insoluble in dilute hydrochloric acid. At C, arsenic, tin and antimony pass on because their sulphides dissolve in boiling sodium hydroxide solution, the remaining five metals being diverted. At D, arsenic passes on because its sulphide dissolves in ammonium carbonate solution, tin and antimony being diverted. Tin passes straight across E because it forms insoluble tin hydroxide with potassium hydroxide and ammonium chloride solution, antimony which stays in solution being "side-tracked".

At F, lead and mercury are "shunted off" because they form insoluble substances when their sulphides are warmed with dilute sulphuric and nitric acid and mixed. At G, lead passes through, because the insoluble lead compound re-dissolves in boiling ammonium acetate solution; the mercury compound, being still insoluble, is "side-tracked".

At H, bismuth is "shunted off" because it forms an insoluble compound when ammonia is added to the solution containing bismuth, copper and cadmium, the other two metals remaining in solution. At J, copper is diverted because of the deep blue colour its salts form with ammonia solution.

At junction III, iron, aluminium and chromium compounds are "side-tracked" because they form insoluble hydroxides with ammonium chloride solution and ammonia. At K, aluminium and chromium are diverted because their hydroxides dissolve when heated with water and sodium peroxide. At L, chromium is "side-tracked" because of the yellow colour of the solution.

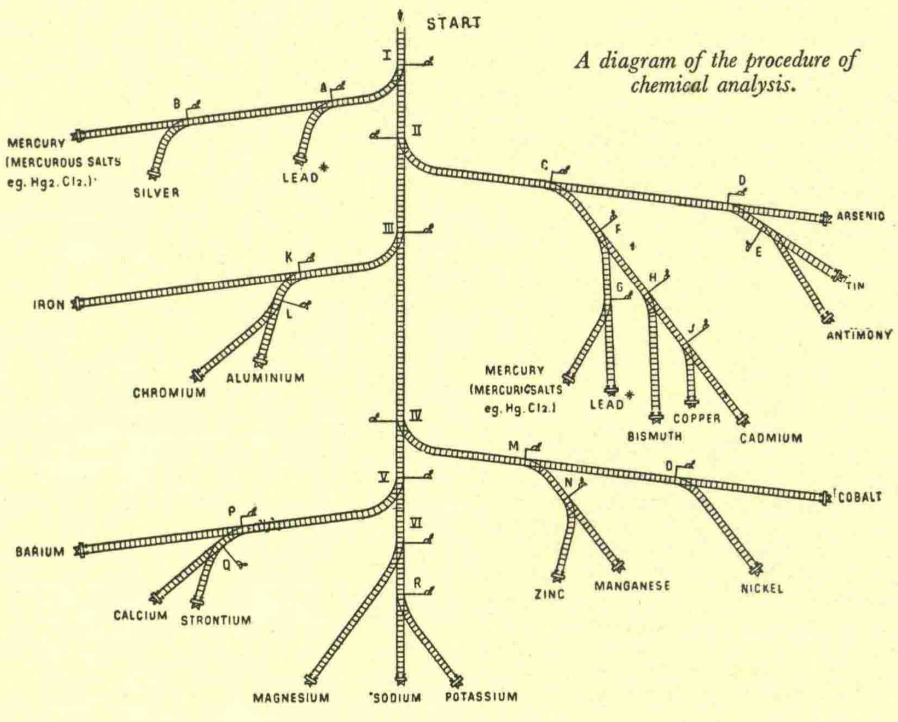
At junction IV, zinc, manganese nickel and cobalt are diverted because they form insoluble sulphides with ammonia solution and sulphuretted hydrogen. At M, zinc and manganese are "side-tracked" because their sulphides dissolve in cold, very dilute hydrochloric acid. At N, manganese is allowed through since it forms a brown precipitate when sodium hydroxide is added to the solution containing manganese and zinc.

The nickel and cobalt sulphides are dissolved in hot concentrated hydrochloric acid and diluted. At O, nickel is diverted when it is recognised by a bright red colour with a complex organic reagent, di-methyl glyoxine.

At junction V, calcium, strontium and barium are "shunted off" because they form insoluble carbonates on boiling with solid ammonium carbonate. Barium is allowed straight through at P because its soluble compounds form a yellow precipitate with potassium chromate solution, calcium and strontium going on to the side-track. At Q, strontium is diverted because it gives a white precipitate of strontium sulphate on boiling with calcium sulphate solution.

At junction VI, magnesium is "side-tracked" when it gives a crystalline precipitate with ammonia and sodium phosphate solution. At R, sodium is recognised and allowed straight through by its ability to turn a bunsen flame bright yellow. Potassium may be shunted-off because of its ability to form a precipitate after standing with tartaric acid.

The exact details of such an analysis, and many confirmatory tests, can be found in any textbook on systematic qualitative inorganic analysis.



A diagram of the procedure of chemical analysis.

Glossary

Absolute Temperature Temperature measured on the Absolute or Kelvin scale (°A or °K). Absolute zero$= -273$°C, which is the lowest temperature theoretically possible. To convert degrees Centigrade to degrees Absolute, add 273.

Acetic Acid, $CH_3.COOH$. A colourless liquid with a pungent smell. Vinegar largely consists of a dilute solution of acetic acid.

Acetone, $CH_3.CO.CH_3$. A colourless and very inflammable liquid with important industrial uses as a solvent.

Acetylene, C_2H_2. An inflammable gas which is given off when water is added to calcium carbide. Used in acetylene lamps.

Acid A compound containing hydrogen which in aqueous solution releases hydrogen (H^+) ions. Normally acids are corrosive, turn litmus red and have a characteristic sour taste. With metals they may form salts and release hydrogen gas, e.g. Zinc + Hydrochloric acid → Zinc chloride + Hydrogen.

Air Air is a complex mixture of gases. Those present in appreciable amounts are nitrogen 78% and oxygen 21%, the remaining 1% including argon, carbon dioxide, neon, helium, krypton and xenon. In addition there may be widely varying amounts of water vapour, dust particles and waste gases from combustion.

Alcohols An important class of organic compounds, each containing one or more hydroxyl (—OH) group; e.g. ethyl alcohol, $C_2H_5.OH$.

Aldehydes A class of organic compounds, each containing the $-\mathrm{C}\genfrac{}{}{0pt}{}{\diagup\mathrm{H}}{\diagdown\mathrm{O}}$ group; e.g. formaldehyde, H.CHO.

Alkali A soluble base which in aqueous solution releases hydroxyl (OH^-) ions. They are normally caustic, turn litmus blue and neutralise acids to give a salt plus water; e.g. sodium hydroxide, NaOH.

Alkali Metals The metals lithium, sodium, potassium, rubidium and caesium.

Alkaline Earth Metals The metals beryllium, magnesium, calcium, strontium, barium and radium.

Allotropy An element existing in two or more forms which may differ widely in physical properties. e.g. Carbon exists as diamonds, graphite and in an amorphous form.

Alloy A mixture of two or more metals. Occasionally an alloy may also contain a non-metal like silicon or phosphorus.

Aluminium, Al, element. A light ductile metal with good corrosion resistance and conductivity of heat and electricity. It is particularly important in alloys which are able to combine lightness with strength; e.g. duralumin.

Alums Double salts with the general formula $X_2SO_4.Y_2(SO_4)_3.24H_2O$, where X is usually potassium or sodium and Y aluminium or chromium; e.g. potash alum, $K_2SO_4.Al_2(SO_4)_324H_2O$.

Amalgam An alloy containing mercury.

Ammonia, NH_3. A colourless, pungent-smelling gas which is extremely soluble in water, giving ammonium hydroxide, NH_4OH. Ammonia is used in refrigerators, fertilisers and explosives.

Ammonium Chloride, sal-ammoniac, NH_4Cl. A white, crystalline solid used in dry batteries.

Ammonium Hydroxide, ammonia solution, NH_4OH. An alkaline solution obtained when ammonia gas is dissolved in water.

Amorphous Non-crystalline. Without any orderly arrangement of molecules in its structure.

Anhydrous A substance in a form containing no combined water; e.g. washing soda, $Na_2CO_3.10H_2O$, can be heated so that water is driven off and anhydrous sodium carbonate powder, Na_2CO_3, is formed.

Aniline, $C_6H_5NH_2$. An oily liquid extracted from coal-tar. Used extensively in dye making.

Anion A negatively charged ion which is drawn to the anode in electrolysis.

Anode The positive electrode.

Antimony, Sb, element. A lustrous silvery metal which is extremely crystalline and brittle. Used with lead and tin in printer's type metal.

Aqua Regia A 4:1 mixture of concentrated hydrochloric and nitric acids, capable of dissolving gold.

Aqueous Used to describe solutions in which water is the solvent.

Asbestos A complex mixture of fibrous silicates, used as a heat insulating material.

Aspirator An apparatus in which one draws a supply of a gas through a liquid.

Atom The smallest whole unit of an element, which cannot be further subdivided by chemical means. An atom of any element consists of a nucleus made up of neutrons and protons surrounded by orbiting electrons. The atoms of the various elements differ only in the number and arrangement of these infinitely small particles.

Atomic Number The number of protons in the nucleus of an atom or alternatively the number of electrons outside the nucleus.

Atomic Weight The weight of an atom of an element compared to the weight of an atom of oxygen which is given the figure 16.

Autoclave A thick-walled vessel in which chemical reactions can be carried out at high temperatures and pressures.

Avogadro's Hypothesis Equal volumes of all gases contain the same number of molecules under identical conditions of temperature and pressure.

Baking Powder A mixture of sodium bicarbonate and tartaric acid which produces carbon dioxide when in contact with water.

Barium, Ba, element. A silvery soft metal which is very reactive.

Barytes Naturally occurring barium sulphate, $BaSO_4$.

Base A substance which releases hydroxyl ions (OH^-) when dissolved in water, and which reacts with an acid to form a salt.

Benzene, C_6H_6. An aromatic hydrocarbon found in coal-tar, which is widely used as a solvent.

Beryllium, Be, element. A hard light metal with good resistance to corrosion, and strength which is retained at high temperatures. It is being used in nuclear engineering.

Bicarbonate An acid salt of carbonic acid, H_2CO_3; e.g. sodium bicarbonate, $NaHCO_3$.

Bitumen A tarry mixture of hydrocarbons.

Bleaching The removal of colour by chemical action.

Bleaching Powder A white powder, prepared by passing chlorine gas into slaked lime, $Ca(OH)_2$. With dilute acids it releases chlorine, which has a powerful bleaching action.

Boiling Point The lowest temperature at which the vapour pressure of a liquid equals the surrounding pressure.

Bond Used to describe the link between one atom and another in a compound.

Borax, $Na_2B_4O_7.10H_2O$. White crystals which dissolve in water, giving an alkaline solution. Borax is used as an antiseptic, and in the manufacture of glass and ceramics.

Borax Bead Test When borax crystals are heated they lose water and eventually form a glass-like bead. Fused borax is able to dissolve various metallic oxides, giving beads of a characteristic colour. This is made use of in the identification of the metal in an oxide or salt.

Boric Acid, H_3BO_3. White crystalline solid which is used as an antiseptic.

Brass A large group of alloys containing copper and zinc.

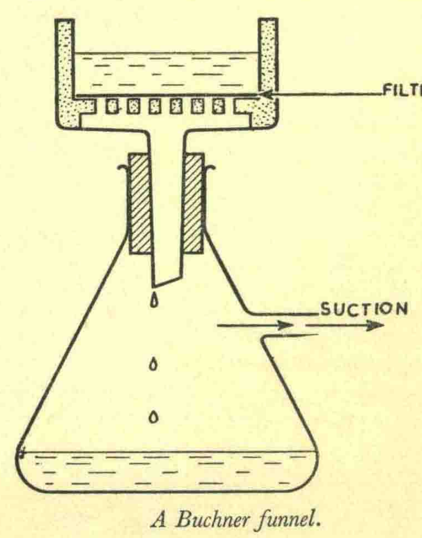
Bromide Any salt of hydrobromic acid, HBr; e.g. potassium bromide, KBr. Bromide paper in photography contains silver bromide, AgBr.

Bromine, Br, element. A reddish brown fuming liquid with a disagreeable smell and which attacks the eyes, nose, throat and skin.

Bronze A group of alloys containing copper and tin.

Brownian Movement The continuous movement of microscopic particles in a suspension; e.g. in a liquid. This movement is caused by the bombardment of the particles by the molecules of the surrounding medium.

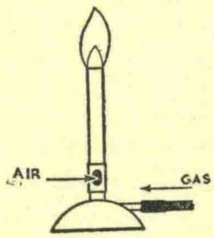
Buchner Funnel A porcelain funnel with a perforated stage, used for filtering under reduced pressure.



A Buchner funnel.

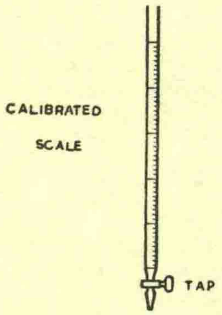
Buffer Solution A solution whose *p*H (hydrogen ion concentration) is not greatly altered by additions of acid or alkali.

Bunsen Burner A laboratory gas burner which has an adjustable inlet to control the amount of air to be mixed with the gas.



A Bunsen burner.

Burette A graduated glass tube fitted with a tap and a fine nozzle at the lower end. Used in volumetric analysis for measuring accurately the amount of liquid run out into another vessel. The capacity of a burette may vary, but they frequently hold 50 millilitres.



A burette.

Calcination The heating of a metal in air so as to convert it to its oxide.

Calcium, Ca, element. A soft silver-white metal, with many widely occurring compounds; e.g. calcium carbonate, $CaCO_3$ (chalk, limestone and marble).

Calcium Carbide, CaC_2. A greyish-white solid which reacts vigorously with water, giving off acetylene gas.

Calcium Carbonate, $CaCO_3$. A white solid which is almost insoluble in water. It occurs naturally as chalk, limestone, marble and in sea shells, egg shells, coral and bones.

Calcium Chloride, $CaCl_2$. A white solid which strongly attracts moisture from the air and eventually dissolves in it.

Calcium Hydroxide Slaked lime, $Ca(OH)_2$. Formed by the action of water on quick lime.

Calcium Oxide, quicklime, CaO. Produced by the action of heat on limestone in a limekiln.

Carat A measure of the purity of gold alloys. Each part of gold by weight in 24 parts of the alloy is called a carat. Pure gold is therefore 24 carat. 14 carat gold contains 14 parts of gold to 10 parts of some other metal or metals.

Carbide A compound of carbon combined with a metal; e.g. calcium carbide, CaC_2.

Carbohydrates A large group of naturally occurring organic compounds including sugars, starches and cellulose. They are built up of atoms of carbon, hydrogen and oxygen.

Carbolic Acid, phenol, C_6H_5OH. An organic solid with powerful antiseptic properties.

Carbon, C, element. Occurs in three allotropic forms—diamonds, graphite and as amorphous carbon. Carbon is present in all living things and the study of its compounds is the vast subject of organic chemistry.

Carbon Dioxide, CO_2. A colourless gas which is present in the atmosphere and dissolved in all natural waters.

Carbon Monoxide, CO. A colourless and extremely poisonous gas. It is produced in the incomplete burning of carbon-containing fuels; e.g. coal, coke, oil. It is therefore found in the exhaust of a motor car.

Carbon Tetrachloride, CCl_4. A heavy liquid which is widely used as a cleaning solvent and in fire extinguishers.

Carbonate A salt of carbonic acid, H_2CO_3: e.g. potassium carbonate, K_2CO_3.

Carbonic Acid, H_2CO_3. A weak acid which is thought to be formed when carbon dioxide dissolves in water.

Carborundum A very hard compound of carbon and silicon which is used as an abrasive.

Catalyst A substance which is able to increase the speed of a chemical reaction without being changed itself.

Cathode The negative electrode.

Cation A positively charged ion which is drawn to the cathode in electrolysis.

Caustic Corrosive to organic material.

Caustic Potash, potassium hydroxide, KOH.

Caustic Soda, sodium hydroxide, NaOH.

Cellulose A carbohydrate which is an essential constituent of plants. Used in making paper, plastics, and textile fibres.

Cellulose Acetate A very clear plastic which is used for making photographic film base and acetate rayon. It is obtained by the action of acetic anhydride on cellulose.

Cellulose Nitrate, nitrocellulose. A range of substances, including plastics and explosives, obtained by the action of a mixture of nitric and sulphuric acids on cellulose.

Cement Portland cement is a complex mixture of chemicals including calcium silicates and aluminates. It is produced by heating a mixture of ground limestone and clay in a kiln.

Centigrade Scale The scale of temperature used for all scientific work. On the scale, the freezing point of water is 0°C and the boiling point of water is 100°C.

Chalk A naturally occurring form of calcium carbonate, $CaCO_3$.

Charcoal Impure amorphous forms of carbon; e.g. animal charcoal, made by heating bones and animal substances.

Chemical Change A process in which the chemical composition of a substance is altered.

Chemical Reaction Two or more substances acting together leading to chemical change.

Chile Saltpetre A naturally occurring form of sodium nitrate, $NaNO_3$.

China Clay, kaolin. A naturally occurring compound of aluminium, silicon, oxygen and hydrogen with uses in the manufacture of paper, porcelain and plastics.

Chloride Salt of hydrochloric acid.

Chlorine, Cl, element. A poisonous yellowish-green gas with an irritating smell. It is two and a half times as heavy as air and was the first poison gas to be used in warfare.

Chloroform, $CHCl_3$. A sweet-smelling volatile liquid which is used as an anaesthetic and as an industrial solvent.

Chromium, Cr, element. A hard white metal capable of taking a very high polish. Used in a range of stainless steels and for chromium plating.

Citric Acid, $C_6H_7O_8$. A white crystalline substance, soluble in water and with a sour taste, which is present in lemons and other citrus fruits.

Coagulation The formation of a curd-like mass in a liquid caused either by the addition of some chemical or by heat; e.g. the addition of an acid to milk.

Coal A complex mixture of carbon compounds in large underground deposits formed by the decomposition of vegetable matter over a period of thousands of years.

Coal-gas The mixture of gases obtained by distilling coal. It mainly consists of hydrogen and methane.

Coal-tar A black liquid obtained by the distillation of coal. Coal-tar contains a large number of carbon chemicals, including benzene, toluene, xylene and naphthalene.

Cobalt, Co, element. A white metal resembling iron which is used in many alloys.

Coke The residue in the production of coal-gas.

Colloid A mixture consisting of very small electrically charged particles distributed in some other substance. Though extremely small, the particles are larger than the single molecules which exist in true solutions. Milk, starch solution, gelatin solution and smoke are all colloidal.

Compound Two or more elements chemically combined together in fixed proportions by weight.

Concentrated A strong solution of a chemical substance.

Condensation Reaction A chemical reaction in which two or more substances are joined together with the elimination of a simple molecule, usually water.

Condenser A vessel in which a vapour is converted to a liquid after distillation.

Copper, Cu, element. A reddish-brown metal which is a very good conductor of heat and electricity. It is malleable and ductile and large quantities are used in electrical equipment, boilers, electrotyping and in numerous alloys.

Copper Sulphate, cupric sulphate, $CuSO_4$. Transparent soluble blue crystals used in electroplating and plant spraying.

Corrosion The action of moisture, air or chemicals on the surface of a material; e.g. the rusting of iron.

Crucible A heat-resistant vessel for chemical reactions.

Crystallography The study of crystal form.

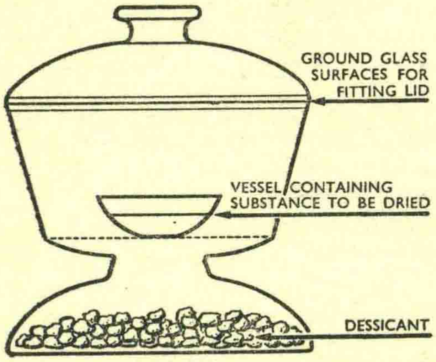
Cyanide A salt of hydrocyanic acid, HCN.

Decomposition The breaking up of a compound into simpler chemical parts; e.g. the action of heat decomposes mercuric oxide into mercury and oxygen.

Dehydration The removal of water from a substance.

Deliquescence A deliquescent chemical will draw in moisture from the air to such an extent that eventually it dissolves in this water.

Desiccator An apparatus used for drying substances in the laboratory. It is an air-tight glass vessel with a compartment to take a quantity of some hygroscopic material; that is, one which draws moisture from the air around it—e.g. calcium chloride.



A desiccator.

Deuterium, heavy hydrogen. An isotope of hydrogen which has a neutron in addition to the single proton in the nucleus of ordinary hydrogen.

Diamond An allotropic form of carbon which is the hardest substance known.

Dilute A weak solution of a chemical substance.

Dissociation The decomposition of molecules of a compound into simpler parts; e.g. heat converts ammonium chloride, NH_4Cl, into ammonia, NH_3, and hydrogen chloride, HCl. Electrolytic dissociation is the breakdown of the molecules of an electrolyte into ions, which are charged atoms or group of atoms; e.g. sodium chloride NaCl in aqueous solution dissociates into sodium Na^+ ions and chloride Cl^- ions.

Distillate The liquid which forms when the vapours from a distillation condense.

Distillation The process of heating a mixture so that at a particular temperature a liquid portion is converted into vapour. This vapour is led into a condenser where cooling converts it again to the liquid state. Distillation is an important method for the separation and purification of volatile liquids.

Dry Ice, solid carbon dioxide, CO_2. Used in refrigeration.

Duralumin A light alloy of good strength containing mainly aluminium with 4% of copper.

Dyes Coloured substances which are soluble in water.

Dynamite An explosive consisting of nitroglycerine absorbed in kieselguhr.

Efflorescence The property of certain crystalline salts which gradually lose their water of crystallisation to the air, becoming powdery on the surface; e.g. washing soda crystals, $Na_2CO_3.10H_2O$.

Electrolysis The chemical decomposition of a compound by passing an electric current through its aqueous solution.

Electrolyte A compound which when dissolved in water will conduct electricity.

Electron One of the three basic particles which comprise atoms. Electrons carry a negative electrical charge and have a mass approximately $\frac{1}{1800}$th that of a proton or neutron.

Ellectropating The application of thin coatings of metal by electrolysis; e.g. chromium plating.

Element A substance consisting of atoms of only one type. There are 92 naturally occurring elements.

Emulsion A mixture in which very small droplets of one liquid are suspended in another liquid.

Enzymes A natural catalyst produced by living cells.

Epsom Salts, magnesium sulphate, $MgSO_4.7H_2O$.

Ether, diethyl ether, $(C_2H_5)_2O$. A sweet-smelling inflammable liquid which is an anaesthetic.

Ethyl Alcohol, alcohol, C_2H_5OH. An inflammable liquid with a characteristic smell. It is normally produced by a fermentation process and is used as an industrial solvent, as a fuel and in alcoholic beverages.

Ethylene Glycol, $(CH_2OH)_2$. Viscous liquid with a sweet taste which forms the basis of commercial anti-freeze mixtures.

Evaporation The process of changing from the liquid to the vapour state.

Filter Funnel A device for separating the solid and liquid portions of a mixture. A porous material, usually paper, is arranged in the funnel so that only the liquid portion can pass through into the vessel below.

Fixing, Photographic The removal of unexposed particles of the light-sensitive silver salt (e.g. silver bromide) after development. If these particles were left on the photographic film the non-image areas would slowly darken. Since the sensitive silver salts are insoluble, a solution of sodium thiosulphate ('hypo') is used to get them into solution.

Fluorine, F, element. A pale yellow gas resembling chlorine.

Formaldehyde, H.CHO. A gas with an unpleasant smell which dissolves in water. Used in making several important plastics.

Formalin A 40% solution of formaldehyde, used as a disinfectant and preservative.

Fractional Distillation The separation of a mixture of several liquids which have different boiling points by collecting the distilled portions which come over at different temperatures.

Freezing Point The temperature at which a liquid changes to a solid state.

Gallium, Ga, element.

Galvanized Iron Iron coated with a layer of zinc.

Gas A state of matter in which molecules have great freedom of movement and occupy all the available volume in a vessel.

Gel A colloidal mixture which has set to a jelly.

Gelatin A complex protein obtained by treating animal bones and cartilages in hot water. Even weak solutions of gelatin set to a jelly on cooling. Gelatin is used in foodstuffs, photography and in printing.

Germanium, Ge, element. A white brittle metal used in transistors.

Glacial Acetic Acid Pure acetic acid.

Glass A mixture of the silicates of calcium, sodium, lead and other metals.

Glauber's Salt Sodium sulphate crystals, $Na_2SO_4.10H_2O$.

Glycerine, glycerol, $C_3H_8O_3$. A sweet viscous liquid, obtained from oils and fats. Used in making explosives, cosmetics and resins.

Gold, Au, element. One of the most malleable and ductile metals with excellent resistance to corrosion by air, water and most chemicals. Used in jewellery and coinage normally alloyed with silver or copper.

Gram-atom The atomic weight of an element in grams.

Gram-equivalent The equivalent weight of a substance in grams.

Gram-molecule The molecular weight of a compound in grams.

Graphite An allotropic form of carbon used as a lubricant and in pencil leads.

Gun-cotton A highly inflammable form of nitrocellulose formed by the action of nitric acid on cellulose.

Gunpowder An explosive mixture of charcoal, potassium nitrate and sulphur in definite proportions.

Hafnium, Hf, element.

Halide A compound of one of the halogens with any metal.

Halogens The elements chlorine, bromine, iodine and fluorine.

Hard Water Water containing compounds which prevent the immediate formation of a lather with soap. The compounds react with the soap forming an insoluble scum with no detergent properties. Temporary hardness, which can be removed by boiling, is due to the presence of calcium and magnesium bicarbonates. Permanent hardness is due to the presence of calcium and magnesium sulphates and chlorides.

Heavy Water Water containing heavy hydrogen atoms (Deuterium).

Helium, He, element. A light unreactive gas which is non-inflammable and therefore useful for filling balloons and airships.

Heterogeneous Uneven composition.

Hydride Compound of an element with hydrogen.

Hydrocarbon Chemical containing hydrogen and carbon combined in some proportion.

Hydrochloric Acid A strong acid formed when hydrogen chloride gas, HCl, is passed into water. Hydrochloric acid has numerous uses in industrial chemistry.

Hydrocyanic Acid, prussic acid, HCN. An extremely poisonous liquid which has a characteristic smell of bitter almonds.

Hydrofluoric Acid A strong acid formed when hydrogen fluoride gas, HF, is passed into water. Hydrofluoric acid attacks glass and is used for etching it.

Hydrogen, H, element. The lightest substance known. Hydrogen gas is colourless, inflammable and odourless. When it burns in air, water is produced.

Hydrogen Ion (H^+) A positively charged atom of hydrogen.

Hydrogen Ion Concentration The number of grams of hydrogen ions in a litre of aqueous solution. A measure of relative acidity and alkalinity expressed on the *p*H scale.

Hydrogen Peroxide, H_2O_2. A liquid miscible with water, which readily gives off oxygen and is therefore useful as a bleaching agent.

Hydrogen Sulphide, H_2S. A colourless gas with the familiar smell of bad eggs.

Hydrolysis The decomposition of a substance by the action of water.

Hypo, sodium thiosulphate, $Na_2S_2O_3$. The normal fixing agent in photography.

Inert Gases The group of unreactive gases comprising helium, neon, argon, krypton, xenon and radon.

Inorganic Chemistry The chemistry of elements and their compounds other than those of carbon.

Insoluble Not capable of dissolving in a solvent which, unless otherwise stated, is water. Few substances are absolutely insoluble.

Iodide Salt of hydroiodic acid, HI; e.g. potassium iodide, KI.

Iodine, I, element. A bluish-black crystalline solid which is only slightly soluble in water. A dilute solution in alcohol is the brown 'tincture of iodine' used medicinally as an antiseptic.

Ion An electrically charged atom or group of atoms.

Ionisation The release of ions by a neutral substance.

Iridium, Ir, element. A rare metal similar to platinum and used for fountain-pen nib-tips and for other purposes demanding great hardness.

Iron, Fe, element. A lustrous grey metal which is strongly magnetic. It is the most important industrial metal, and usually it is produced as an alloy with other metals and carbon.

Isomers Compounds having the same molecular formula but with a different arrangement of atoms in the molecules. Two isomers will have different chemical and physical properties.

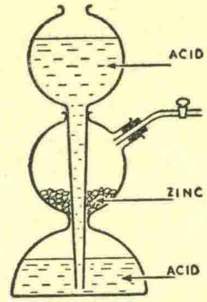
Isotopes Atoms of the same element, differing only in the number of neutrons in the nucleus. Two isotopes will have different atomic weights but identical chemical properties.

Ketones A class of organic compounds; e.g. acetone, $(CH_3)_2CO$.

Kipp's Apparatus A laboratory apparatus to supply any gas which is produced by the action of a liquid on a solid without the application of heat; e.g. to supply hydrogen by the action of dilute sulphuric acid on zinc. On opening the tap the acid rises into the middle section and attacks the zinc (*see top centre*).

Krypton, Kr, element. An unreactive gas occurring in very small quantities in the atmosphere.

Lamp-black An allotropic form of carbon. Soot.



Kipp's apparatus.

Lanoline A waxy constituent of wool grease used in ointments.

Laughing Gas, nitrous oxide, N_2O. A gas used as an anaesthetic.

Lead, Pb, element. A soft bluish-grey metal. Its metallic lustre, when freshly cut, soon disappears if it is left in contact with the air. It is resistant to water and most acids. This fact, and the ease with which it can be worked, soldered and cut, makes lead suitable for water pipes. Lead is also a component of many alloys including pewter, solder and printer's type metal.

Lead-chamber Process A process for the manufacture of sulphuric acid.

Lime, quicklime, calcium oxide, CaO. A white powder produced by the action of heat on limestone in lime-kilns. Slaked lime, $Ca(OH)_2$, is formed when water is added to quicklime.

Limestone A naturally occurring form of calcium carbonate, $CaCO_3$.

Limewater A solution of calcium hydroxide, $Ca(OH)_2$, which is made cloudy when carbon dioxide, CO_2, is passed through it. This is used as a means of identifying carbon dioxide.

Liquid A state of matter intermediate between a solid and a gas where the molecules are in restricted motion.

Lithium, Li, element. A white metal which is similar to sodium. Lithium has the lowest density (0.534) of any solid element.

Litmus A dye obtained from certain lichens which is turned red by acid solutions and blue by alkaline solutions. Used as an indicator.

Litre The volume of a kilogram of pure water at 4°C and 760 mm. pressure. A litre is divided into 1,000 millilitres. These and also cubic centimetres are used as the units of volume in chemical work.

Magnesium, Mg, element. A light silvery-white metal which burns in air with a brilliant white flame. Magnesium is extensively used in lightweight alloys; e.g. duralumin.

Magnesium Sulphate, Epsom salts, $MgSO_4.7H_2O$. A white soluble salt.

Manganese, Mn, element. A hard brittle grey metal used in steels and other alloys.

Manganese Dioxide, MnO_2. A black powder used as a catalyst in the laboratory preparation of oxygen from potassium chlorate.

Melting Point The temperature at which a solid passes into the liquid state.

Mercury, Hg, element. A silvery-white metal which is the only one that is liquid at ordinary temperatures. Used in thermometers, barometers and other scientific instruments.

Mercury Vapour Lamp A lamp giving a predominantly blue light which is emitted when an electrical current is passed through mercury vapour.

Metal A term applied to a large group of elements which are generally lustrous, ductile, malleable, of high specific gravity and good conductors of heat and electricity. Metal oxides have the ability to neutralise acids.

Methyl Alcohol, wood alcohol, CH_3OH. A colourless poisonous liquid which is added to ethyl alcohol in 'methylated' spirits.

Methylated Spirits A mixture consisting mainly of ethyl alcohol (90%) together with methyl alcohol, pyridine, oils and a blue dye. Used as a solvent and as a fuel.

Methylated Spirits, Industrial, IMS. A mixture of ethyl and methyl alcohols without the pyridine and other additives in normal methylated spirits.

Methyl Orange A dye used as an indicator for acids (pink) and alkalis (orange).

Millilitre Unit of volume. $\frac{1}{1000}$th of a litre.

Mineral Oil Mixture of hydrocarbons obtained by the distillation of petroleum oil.

Miscible Capable of mixing; e.g. alcohol and water.

Mixtures Materials which are not single pure elements or compounds but some combination of them. The constituents of a mixture can usually be separated by physical means. Examples of mixtures: paper, sea water, air.

Molar Solution A solution containing one gram molecule of a substance in a litre.

Molybdenum, Mo, element. A hard white metal used in alloys.

Moth-balls, naphthalene, $C_{10}H_8$.

Naphthalene, $C_{10}H_8$. A white strongly smelling crystalline substance present in coal-tar. Used in the manufacture of pigments and dyes.

Nascent The active state of a gas at the moment it is given off from a chemical reaction; e.g. nascent hydrogen and nascent oxygen are both far more chemically active than the normal gases.

Natural Gas A mixture of gases occurring underground.

Neon, Ne, element. An unreactive gas which is present in very small quantities in the air. Neon lamps emit an orange-red light obtained by passing an electrical current through neon gas at low pressures.

Neutral Showing neither an acid nor an alkaline reaction.

Neutron One of the constituents of the nucleus of all atoms except hydrogen. Neutrons carry no electrical charge and they have a mass similar to that of a proton.

Nickel, Ni, element. A silvery-white metal with excellent resistance to corrosion. Used for nickel plating and in alloys.

Nickel Plating The application of a thin layer of nickel by electrolysis. Frequently used as a base for chromium plating.

Nitrate A salt of nitric acid, HNO_3.

Nitration The use of nitric acid to introduce the nitro group, NO_2, to a substance. An important chemical reaction in the manufacture of explosives.

Nitric Acid, HNO_3. A colourless, fuming liquid which is a powerful oxidising acid. It attacks most metals, giving off brown fumes of nitrogen peroxide, NO_2. Widely used in the chemical industry, especially in the manufacture of explosives, colours, plastics and silver nitrate for photographic purposes.

Nitric Oxide, NO. A colourless gas which forms nitrogen peroxide, NO_2, on contact with air.

Nitrocellulose *See* Cellulose nitrate.

Nitrogen, N, element. An odourless and colourless gas which makes up about four-fifths of the atmosphere. Nitrogen gas is unreactive. The element is essential to life.

Nitrogen Peroxide, nitrogen dioxide, NO_2. Dark brown gas with an unpleasant smell.

Nitroglycerin Pale yellow liquid which explodes on detonation. Made by the action of nitric and sulphuric acids on glycerine. Used as an explosive.

Nitrous Oxide, N_2O. *See* Laughing gas.

Noble Metals Gold, silver and platinum, so called because they have good resistance to tarnishing.

Normal Solution A solution containing 1 gram equivalent of a substance in 1 litre.

Nucleus The central core of an atom consisting normally of protons and neutrons and carrying a positive electrical charge.

Nylon A long chain carbon compound suitable for use as a textile fibre. Ordinary nylon is produced from hexamethylene diamine and adipic acid.

Organic Chemistry The chemistry of carbon compounds.

Osmosis The flow of a solvent through a semi-permeable membrane; i.e. a membrane which will allow the passage of solvent molecules but not the larger molecules of the dissolved substance.

Oxidation A reaction in which a substance gains oxygen or loses hydrogen. In its broadest terms, a reaction in which a substance loses an electron.

Oxidising Agent A reagent which causes another substance to be oxidised.

Oxygen, O, element. A reactive odourless gas which forms about a fifth of the atmosphere and also occurs in numerous compounds. Essential to most forms of life.

Ozone, O_3. An allotropic form of oxygen. A gas with strong oxidising properties.

Paraffin Hydrocarbons A series of hydrocarbons, with the general formula C_nH_{2n+2}, present in petroleum. Methane gas, CH_4, is the first member of the series.

Paraffin Wax A white solid which consists of a mixture of some of the higher members of the paraffin hydrocarbon series.

Penicillin A class of antibiotics which are able to prevent the growth of certain types of bacteria.

Periodic Table The elements arranged in order of their atomic numbers in such a way that they fall into related groups. The properties of an individual element are usually related in some way to the properties of its neighbouring elements in the table.

Peroxide An oxide, containing a large proportion of oxygen, which is converted into hydrogen peroxide, H_2O_2, with an acid; e.g. lead peroxide, PbO_2.

Petrol A mixture of hydrocarbons mainly from the paraffin series. Used as a fuel.

Petroleum A naturally occurring complex mixture of hydrocarbons. Fractional distillation and cracking of crude petroleum gives us petrol, paraffin, lubricating oils, greases and waxes.

Pewter An alloy of tin and lead.

***p*H Scale** A scale on which to measure the relative acidity and alkalinity of aqueous solutions.

Phenolphthalein A colourless solid whose solution in alcohol provides a useful indicator for acids (colourless) and alkalis (turns red).

Phosphate A salt of phosphoric acid, H_3PO_4.

Phosphoric Acid, H_3PO_4. A colourless, syrupy liquid which is a strong acid.

Phosphorus, P, element. Occurs in several allotropic forms, including white phosphorus and red phosphorus, which have quite different properties. Phosphorus exists in a large number of compounds and it is essential to life.

Pigments Colouring matters which are insoluble in water.

Pipette A glass tube used for transferring a measured volume of liquid from one vessel to another.

A pipette.

Plaster of Paris, calcium sulphate, $(CaSO_4)_2H_2O$. A white powder obtained when the naturally occurring gypsum, $CaSO_4.2H_2O$, is heated to 120°C. When plaster of paris is mixed with water it sets to a hard mass.

Plastics Solid materials which at some stage of their manufacture are made plastic by the application of heat and pressure so that at this stage they can be given a new shape. Plastics are normally organic polymers and they can be classified into two groups, thermosetting and thermoplastic.

Platinum, Pt, element. A silvery-white metal which is harder than silver or gold, ductile, malleable, and with good resistance to corrosion. Platinum is used as a catalyst for chemical reactions and in jewellery.

Polymer A compound consisting of large molecules which have been formed by the joining up of a large number of simple molecules (monomers). Most plastics and synthetic fibres are polymers.

Polythene, polyethylene. A tough thermoplastic material with a waxy feel produced by the polymerisation of ethylene, C_2H_4. Used in packaging as a protective film, for water pipes, for insulation and for many other industrial and household purposes.

Polyvinyl Chloride, PVC. A rubber-like thermoplastic material produced by the polymerisation of vinyl chloride. Many uses, including the manufacture of plastic raincoats.

Potassium, K, element. A soft white metal, very similar to sodium. Potassium forms a large number of salts.

Potassium Carbonate, potash, K_2CO_3. A white soluble deliquescent salt.

Potassium Dichromate, potassium bichromate, $K_2Cr_2O_7$. A red soluble crystalline salt which is a powerful oxidising agent.

Potassium Hydroxide, caustic potash, KOH. A white deliquescent solid which dissolves in water to give a strongly alkaline solution.

Potassium Nitrate, saltpetre, KNO_3. White soluble crystals used in the manufacture of gunpowder.

Potassium Permanganate, $KMnO_4$. Dark purple crystals with a greenish lustre which are soluble in water. Potassium permanganate solutions have an oxidising action and they are used as a disinfectant.

Precipitate An insoluble substance formed in a chemical reaction.

Proton A positively charged particle which is present in the nuclei of all atoms. The nucleus of an ordinary hydrogen atom consists of one proton.

Prussic Acid A solution of hydrocyanic acid, HCN. A deadly poison.

Qualitative Analysis The identification of the types of substances present in a material.

Quantitative Analysis The determination of the amounts of particular substances present in a material.

Quicklime, calcium oxide, CaO. *See* Lime.

Quicksilver, mercury, Hg.

Radical, Radicle. A group of atoms which remain together and act as a unit in chemical reactions; e.g. the nitrate radical NO_3, the ammonium radical NH_4.

Radioactivity A natural breakdown of the unstable nuclei of atoms usually of high atomic weight. Charged particles are given out (e.g. alpha or beta particles) and the radioactive element eventually is left with a more stable nucleus. Today almost any element can be made radioactive by bombarding it with neutrons in an atomic pile. The resulting radioactive isotopes have many useful applications in medicine and industry.

Radium, Ra, element. A rare naturally occurring radioactive metal.

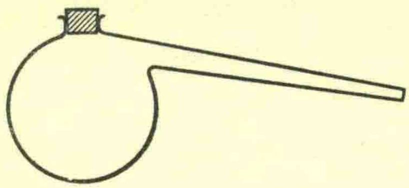
Rayon A regenerated and slightly modified form of cellulose used as a textile fibre; e.g. viscose rayon and cellulose acetate.

Reaction Two or more substances acting together leading to a chemical change.

Reducing Agent A reagent which brings about the reduction of a substance.

Reduction A reaction in which a substance loses oxygen, gains hydrogen or, in the broadest terms, gains electrons.

Retort A vessel usually made of glass with a large bulb and a long tapering neck in which distillations are carried out.



A retort.

Reversible Reaction A chemical reaction which to some extent moves both forwards and backwards. Conditions can be altered to favour one of the directions; e.g.

$$Na_2CO_3+2H_2O=2NaOH+H_2CO_3.$$

Sal Ammoniac, ammonium chloride, NH_4Cl.

Salt A chemical compound formed when the hydrogen in an acid is replaced by a metal; e.g. common salt (sodium chloride, NaCl) from hydrochloric acid, HCl.

Sand Hard fine particles mainly composed of silica, SiO_2.

Saturated Solution A solution which has the maximum amount of solute dissolved in it at a particular temperature.

Sea Water A complex mixture of dissolved salts including sodium chloride, magnesium chloride and magnesium sulphate.

Silica, silicon oxide, SiO_2. A hard white solid which occurs naturally in the forms of quartz and flint.

Silicate A salt of silicic acid, H_2SiO_3. A great many rocks consist of the silicates of various metals.

Silicon, Si, element. A non-metallic substance which resembles carbon. Occurs naturally in silica and silicates. A constituent of silicones and several alloys.

Silver, Ag, element. A white lustrous metal which is malleable, ductile and the best known conductor of electricity. Used in jewellery and coinage. Its compounds are important in photography, and the black areas on a negative or print do in fact consist of metallic silver in a finely divided form.

Silver Nitrate, $AgNO_3$. A white soluble crystalline solid. Used in medicine, marking inks and in the manufacture of photographic materials.

Silver Plating The application of a thin layer of metallic silver by electrolysis.

Slag Waste material formed during the smelting of metallic ores.

Slaked Lime, $Ca(OH)_2$. *See* Lime.

Smelting The extraction of a metal from its ores, usually by chemical reduction.

Smoke A fine suspension of minute particles of a solid in a gas.

Soap A mixture of metallic salts of organic acids usually obtained by the action of caustic soda on fats and oils; e.g. sodium stearate, $C_{17}H_{35}.COONa$.

Soda Water Water containing dissolved carbon dioxide gas, CO_2, under pressure.

Sodium, Na, element. A very soft white metal which only shows a metallic lustre when freshly cut. A most reactive substance, especially with water, from which it releases hydrogen and forms sodium hydroxide, NaOH. Sodium exists naturally in a wide range of compounds.

Sodium Bicarbonate, 'baking soda', $NaHCO_3$. A white crystalline solid which is a constituent of baking powder.

Sodium Carbonate, 'washing soda', $Na_2CO_3.10H_2O$. White crystals used in softening water. Anhydrous sodium carbonate, Na_2CO_3, is a white powder.

Sodium Chloride, common salt, NaCl. White crystals which are moderately soluble in water. Apart from seasoning, it is used for preserving food and in the manufacture of several important chemicals.

Sodium Hydroxide, caustic soda, NaOH. White soluble deliquescent solid with the characteristic 'soapy feel' of an alkali. Numerous uses in industry.

Sodium Nitrate, $NaNO_3$. White soluble crystals used as a fertiliser.

Sodium Silicate, Na_2SiO_3. Commercial form known as 'Waterglass'.

Sodium Sulphate, Glauber's salt, $Na_2SO_4.10H_2O$. White soluble crystals used in dyeing.

Sodium Thiosulphate, 'hypo', $Na_2S_2O_3$. White soluble crystals used in the fixing of a photographic image.

Solders A range of alloys, commonly consisting of tin and lead, used for joining metals.

Solubility The extent to which a substance will dissolve in a solvent. It is usually expressed as the number of grams which will dissolve in 100 grams of the solvent at a particular temperature.

Soluble Able to be dissolved in a particular solvent which, unless otherwise specified, is water.

Solute The substance to be dissolved in a solvent to form a solution.

Solution A homogeneous mixture of two or more substances, usually referring to a mixture of a solid in a liquid.

Solvent A substance normally a liquid which is able to dissolve another substance.

Stable Used to describe a substance which shows little tendency to decompose.

Steel Iron containing 0.1% to 2.0% of carbon and possibly small quantities of other metals.

Strontium, Sr, element. A white reactive metal resembling calcium.

Sublimation The changing of a substance from a solid to a gas without first melting; e.g. iodine vaporises on heating.

Sulphate A salt of sulphuric acid, H_2SO_4.

Sulphide A salt of hydrogen sulphide, H_2S.

Sulphite A salt of sulphurous acid, H_2SO_3.

Sulphur, S, element. A non-metallic substance which can exist in several allotropic forms. A yellow solid, insoluble in water. Used in the manufacture of sulphuric acid, as an insecticide and for vulcanising rubber.

Sulphur Dioxide, SO_2. A colourless gas formed when sulphur burns in air. Used in refrigeration.

Sulphuric Acid, H_2SO_4. A colourless heavy liquid (specific gravity 1.84). A very strong acid, corrosive to the skin and to all organic matter. A vital substance in the chemical industry.

Supersaturated Solution A solution which contains more of the solute than a saturated solution does at that particular temperature.

Suspension A mixture in which very small particles are held up in a liquid.

Synthetic A substance which has been built up artificially from simpler chemical units.

Thermoplastic A plastic which can be repeatedly softened by heat without any change in its properties.

Thermosetting Plastic A plastic which on heating increases its molecular weight and changes its properties. Heat treatment can therefore only be used once to shape thermosetting plastics, whereas thermoplastics can be heated and reshaped indefinitely.

Tin, Sn, element. A white lustrous metal which is malleable, ductile but rather soft. Unaffected by air and water under normal conditions. Used for tin-plating and in many alloys including solders and type metals.

Titanium, Ti, element. A metal resembling iron. Titanium dioxide, TiO_2, is a white pigment with outstanding opacity.

Titration A method in volumetric analysis in which one solution is slowly added from a burette to a measured amount of a second solution which will react with it. Titration is continued until an 'end point' is reached, usually shown by a colour change in the mixed solutions. At this point the added solution has reacted with all of the solution in the lower vessel. If the strength of one solution is known, the strength of the other can be calculated.

Toxic Poisonous.

Trinitrotoluene, TNT, $C_6H_5.C(NO_2)_3$. An explosive yellow solid obtained by the nitration of toluene.

Type Metals A range of alloys containing lead, tin and antimony.

Unstable Used to describe a substance which has a tendency to decompose.

Uranium, U, element. A hard white radioactive metal which can be made to undergo nuclear fission by bombarding it with neutrons.

Viscose Rayon A regenerated and modified form of cellulose made from wood, used as a textile fibre and as a packaging film.

Vitamins A group of complex organic compounds, present in foods in small amounts and necessary constituents of a healthy diet.

Volatile Evaporating easily into a vapour.

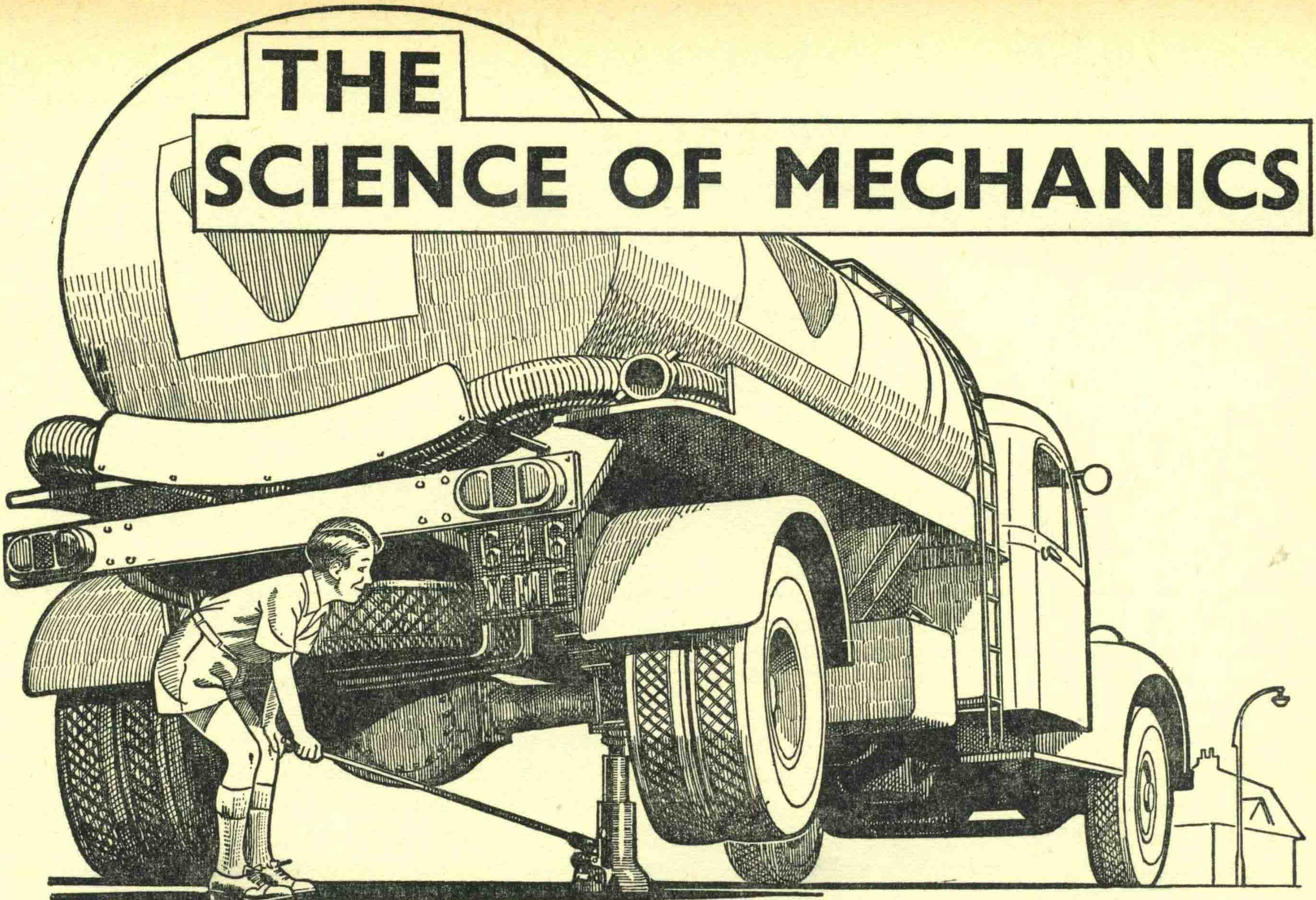
Washing Soda, $Na_2CO_3.10H_2O$. Crystals of sodium carbonate.

Water of Crystallisation A definite molecular proportion of water which is present in the crystals of various salts; e.g. sodium carbonate crystals, $Na_2CO_3.10H_2O$, and copper sulphate crystals, $CuSO_4.5H_2O$.

White Spirit A mixture of hydrocarbons obtained from petroleum distillation. Used as a solvent, especially in the paint industry.

Zinc, Zn, element. A bluish-white metal with a brittle, crystalline structure. Used is several alloys, notably brass, and as the coating material on galvanised iron.

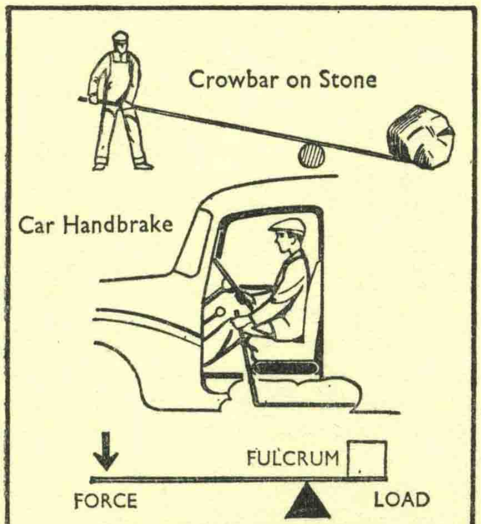
THE SCIENCE OF MECHANICS



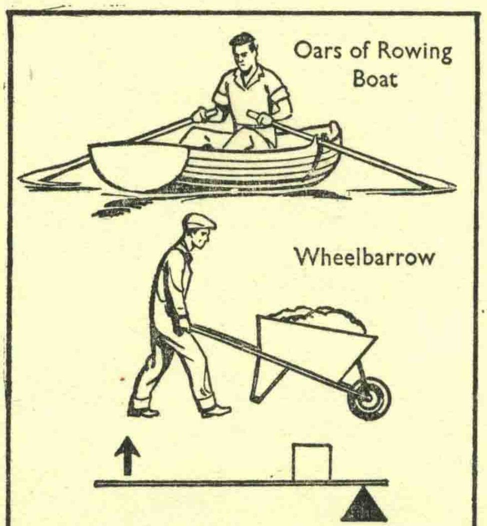
Without the aid of a simple machine, it would be impossible for this boy even to attempt to lift the lorry. By using a jack in the picture he will be able to lift perhaps ten tons to a height of six inches or so. The amount of energy needed is the same whether the jack is used or not, but this simple machine enables the energy to be spent over a longer period of time, reducing the amount used at any given moment.

Machines do not create energy, but they do enable it to be used to the maximum effect. The amount of work a machine does is never more than that put into it. The machine's usefulness is that it enables a lot of movement with a little force to be converted into a little movement with a lot of force. Thus simple machines may be described as devices for concentrating energy.

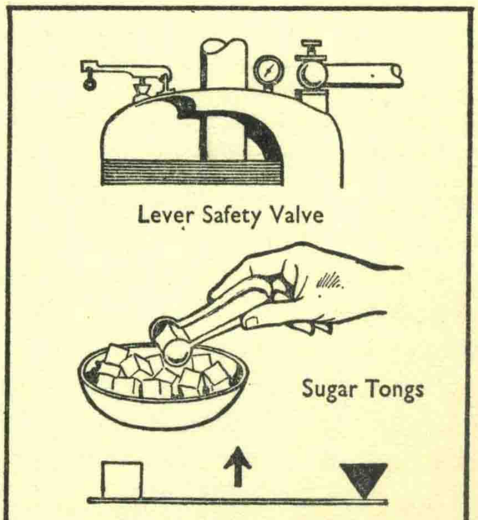
Simple machines may be grouped under the following headings: levers (bars free to move on a pivot), wheels and axles (a form of lever, where the fulcrum is the axle), cranks (used for applying an oblique force to a wheel lever), and pulleys, gears, and inclined planes (see following page). There are three orders of levers (see diagrams below).



Levers of the first order.

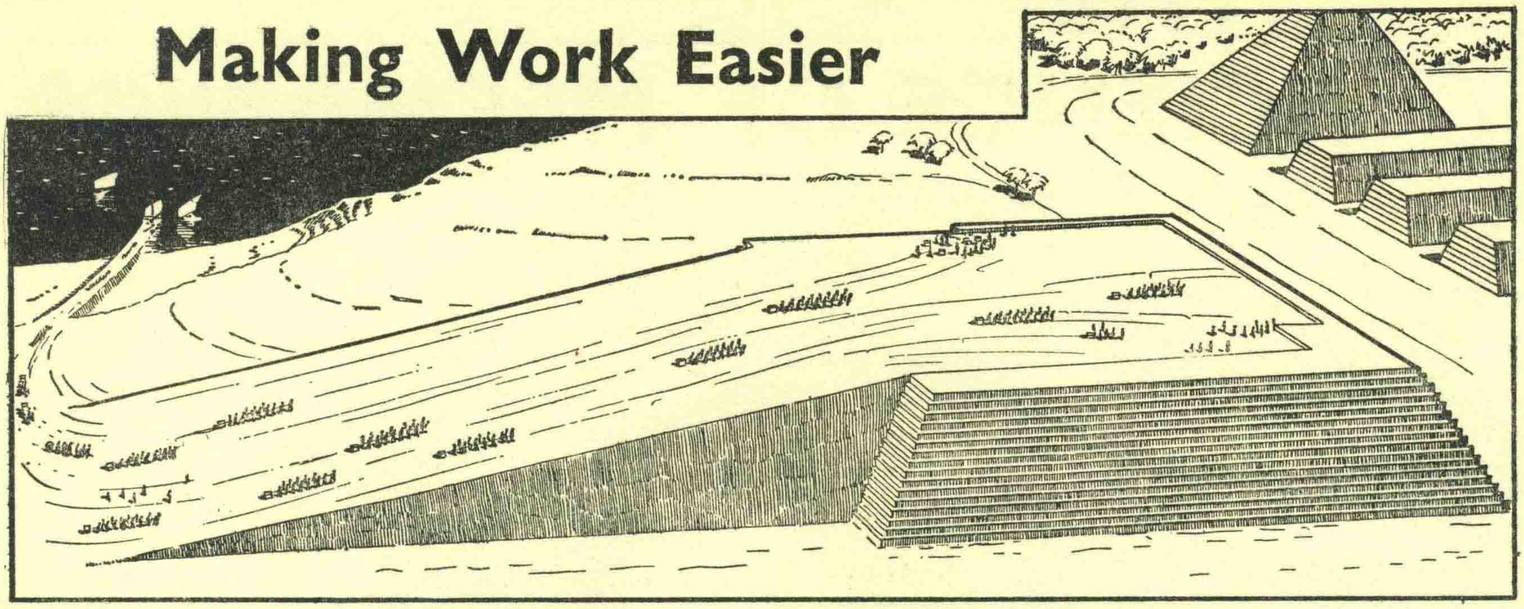


Levers of the second order.



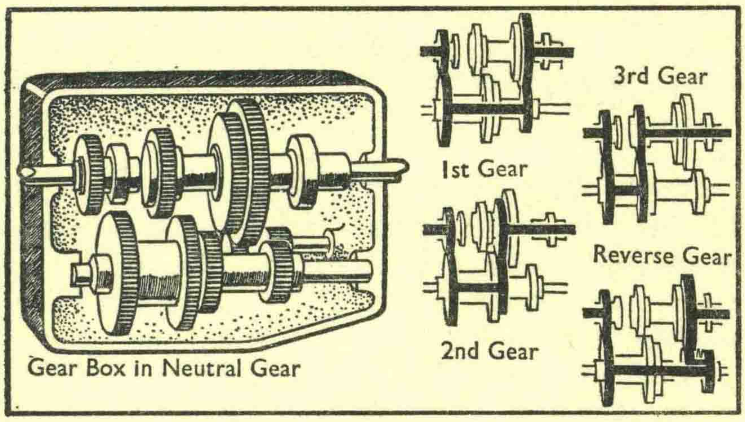
Levers of the third order.

Making Work Easier



When the Egyptians built the Pyramids, there were no engines to pull the blocks of stone, and all the heavy work was done by manpower alone. To raise the stones to the level required they used an inclined plane, a ramp which enabled loads to be brought to the top using less force over a longer period of time. Another form of the inclined plane is the screw, the plane (in this case) being on a spiral thread.

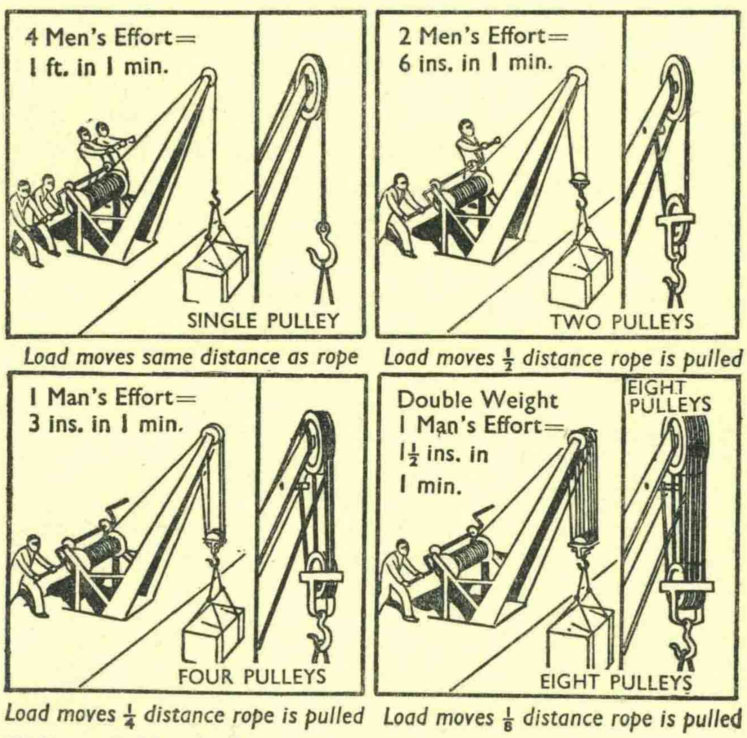
Where there is a limit to the amount of power available, it is essential that it is put to the greatest possible advantage. The inclined plane as shown above was the best method the Egyptians could devise for solving their particular problem. Even today this simple machine has many uses. More complex machines, however, have become necessary.



The gear box of a motor car combines gear wheels of various sizes to allow different ratios between the drive from the engine and the transmission to the wheels. Most cars have a choice of three or four forward gears and a reverse gear. For moving off, a low ratio is used, where the wheels turn very much slower than the engine. When there is less strain, and the car is already moving fast, a much higher ratio is used so that the wheels are turned faster.

The basic idea of the gear is to have two wheels of different sizes meshed together so that they are caused to turn at different speeds. Usually the gear wheel attached to a source of power is small, and the other (attached perhaps to the rear wheels of a car) is larger. The small wheel revolves at great speed but with little power, and engages the teeth of the larger wheel, which turns more slowly but with more power.

The pulley is an ingenious method of raising a load. The single type saves no force, but merely changes the direction of the force. Double and triple pulley blocks, however, divide the load amongst the pulley blocks, and enable the man pulling the rope to lift more than he normally can. No energy is saved, for the rope has to be pulled for a longer distance (though with less force) than the load is raised.



Load moves same distance as rope *Load moves $\frac{1}{2}$ distance rope is pulled*

Load moves $\frac{1}{4}$ distance rope is pulled *Load moves $\frac{1}{8}$ distance rope is pulled*

Pulleys divide the load among the ropes running round the pulley blocks. They do not save work, since the end of the rope has to be pulled further to raise the weight through the same distance. They do, however, allow one man to do the work of several; but the process will take several times as long.

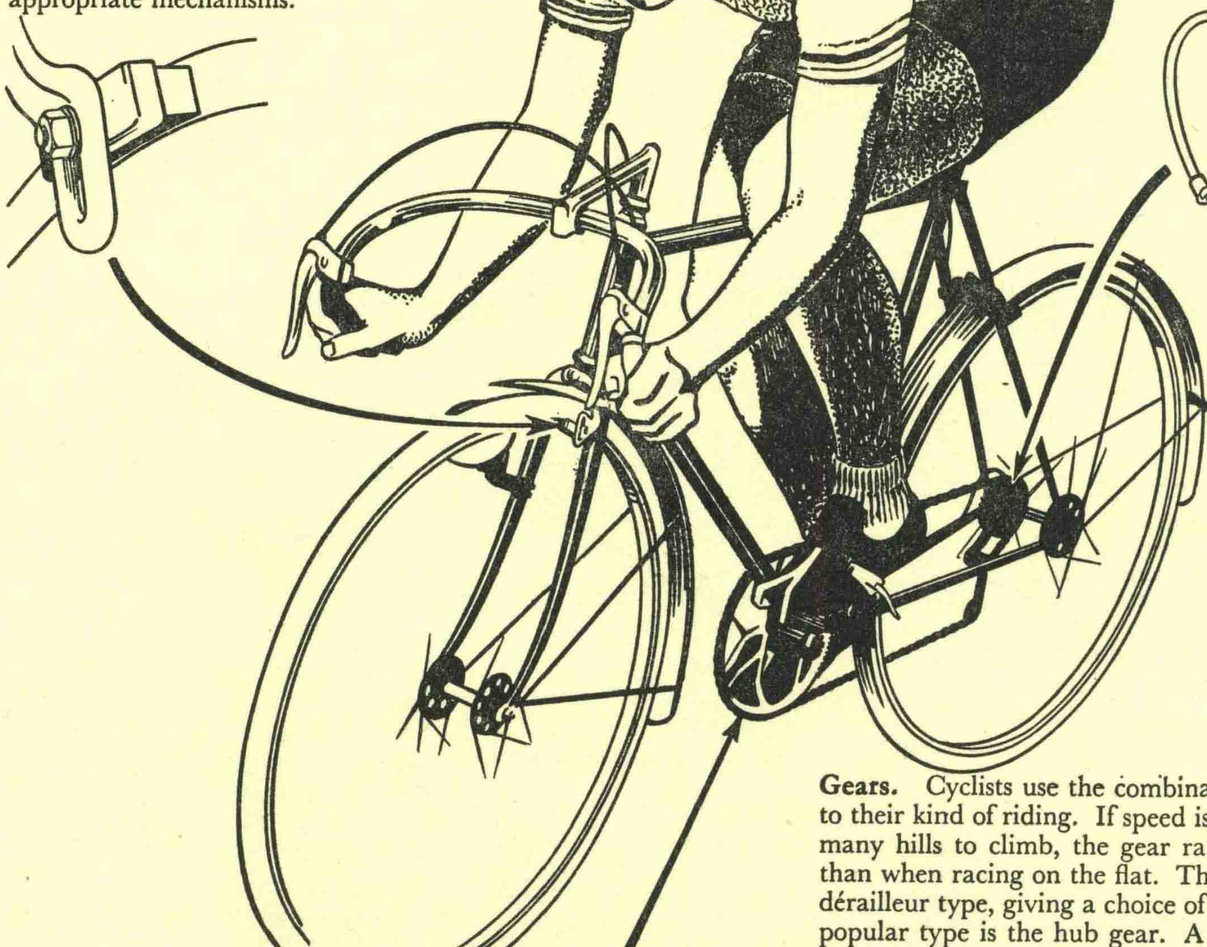
Using Mechanics

Mechanics is the science of moving things, and it is not surprising that it is one of the most important sides of engineering. All large and complicated machines are built up to a great extent from the simple machines described earlier. A bicycle might appear to be a very simple machine itself, but, as the picture shows, it is a combination of several simpler ones, and involves many other principles too.

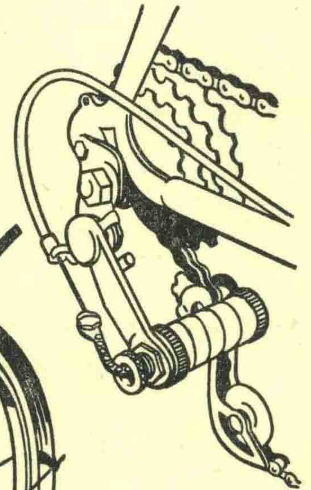
The science of mechanics is concerned with other things apart from machines, especially forces, stability, inertia, friction, and power. These are described in greater detail in the following pages.

Inertia. A head guard may be worn so that, if a sudden stop has to be made and the inertia of the rider's body carries it on (over the handlebars!), less harm will be done.

Levers. Amongst the many kinds of levers on the cycle, the brake and gear change levers on the handlebars are attached to cables which work the appropriate mechanisms.

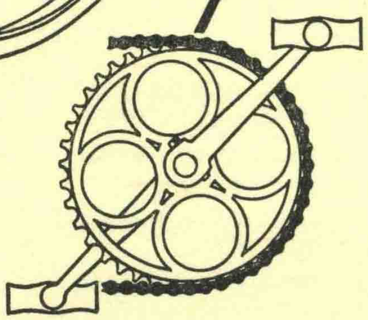


Equilibrium. Balance is maintained in two ways. The rider leans and moves his centre of gravity over the wheels, and also uses the handlebars to make any corrections sideways.



Gears. Cyclists use the combination of gears best suited to their kind of riding. If speed is no object and there are many hills to climb, the gear ratios will be much lower than when racing on the flat. The gears shown are of the dérailleur type, giving a choice of 3 or 4 ratios. The other popular type is the hub gear. A combination of the two types, though rarely used, can give a choice of up to 16 different ratios.

Friction. Without friction between the tyres and the road surface the wheels would spin round without the cycle moving at all! Too much friction, on the other hand, will tend to slow the cycle down. Tyre treads allow just the right amount of friction when moving and give ample safety when braking.

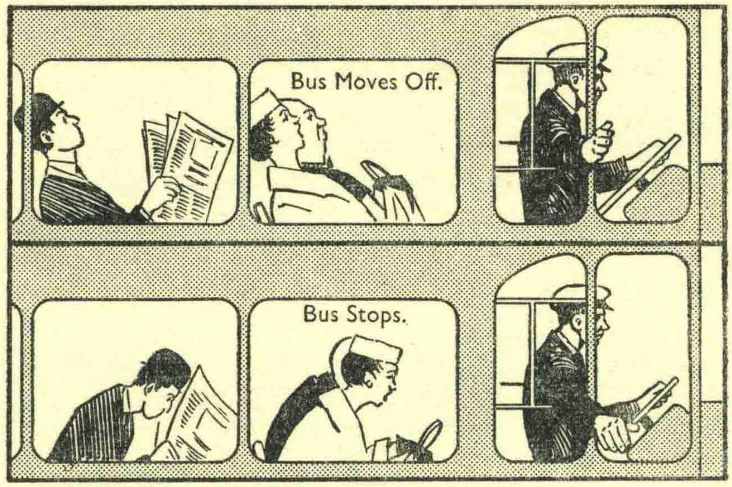


Cranks and Pulleys. The pedals are attached to the chain wheel, and extend outside it. Since they are farther from the fulcrum than the edge of the chain wheel, additional leverage is gained. The chain from the chain wheel runs on a simple pulley to the smaller rear wheel hub, the gear ratio being changed.

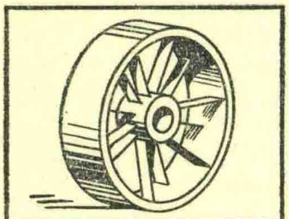
Friction and Inertia

Without friction our lives would be made very difficult indeed. We should not be able to run or walk without falling over, nor should we be able to grip anything in our hands. Friction means rubbing, and it is this which causes things to wear out, and also enables two surfaces to grip against each other.

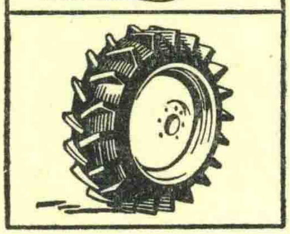
Inertia may be compared with laziness. It is the reason why stationary objects do not move without some force being applied to them and why moving objects "prefer" to continue moving rather than to stop. It is much harder, for example, to budge a railway wagon standing still in a goods yard than to keep it moving once it has started. Again, it is difficult to stop it when it is on the move. Inertia may be defined as the tendency of a body to remain in a state of rest or uniform motion in a straight line.



Inertia causes the passengers in the bus to lean backwards as the bus moves off. When it slows down and stops, they lean forwards.



Friction is low between the ground and a shiny metal tyre. There is little wear of the tyre, but since it does not grip well there is a strong tendency to skid when the brakes are applied.



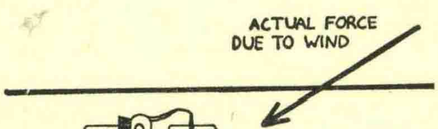
With a soft moulded rubber tyre the friction between ground and tyre will be at its maximum. There is a very good grip, and little chance of skidding, but the friction will tend to wear out the tyre quickly.

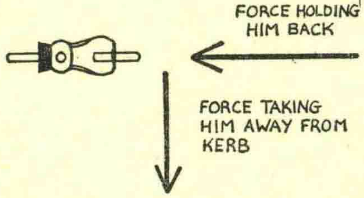
Laws and Forces of Mechanics

FORCES

THE RESOLUTION OF A FORCE INTO COMPONENT FORCES

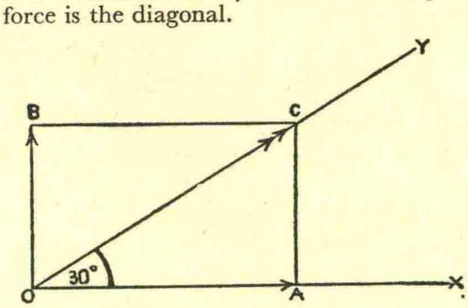
It is often convenient to consider one force as two separate forces; for example, a wind diagonally across a road is best considered as exerting two distinct forces on a cyclist, one along the line of the road, holding him back, and one at right angles urging him away from the kerb.





Example: A man pushes a barrow with a force of 50 lb. up a slope of 30°. Resolve this force into vertical and horizontal components.

Construct a parallelogram with vertical and horizontal sides, of which the given force is the diagonal.



Scale: 1 in.=40 lb.

Construction: OX is horizontal. Angle YOX is 30°. OC is made 1·25 in. long. CA is drawn vertical. CB is parallel to OA and OB to AC. OA represents the horizontal component, 43 lb. OB represents the vertical component, 25 lb.

THE RESULT OF THE ACTION OF MORE THAN ONE FORCE ON A BODY

(a) *When the forces are parallel to each other the resultant is the sum of the various forces.*

Example 1: 10 lb. vertically downward, 5 lb. vertically downward.

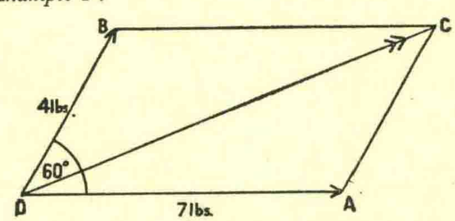
Resultant = 10 + 5 = 15 lb. vertically downward.

Example 2: 12 lb. vertically downward, 9 lb. vertically *upward.*

Resultant $= 12 + (-9) = 12 - 9 = 3$ lb. vertically downward.

(b) *When the forces are not parallel. The parallelogram of forces is needed.*

Example 1:

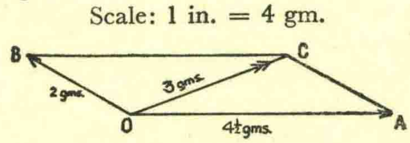


Scale: 1 cm. = 2 lb.

OA represents a horizontal force of 7 lb. OB represents a force of 4 lb. at an angle of 60° to the horizontal. The parallelogram is completed (OBCA). OC represents the "resultant" or the combined effect of the two forces. It is a force of 9·6 lb. acting in the direction OC.

Example 2:

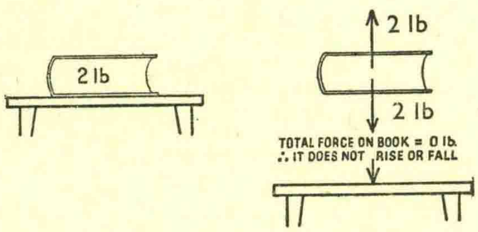
Scale: 1 in. = 4 gm.



ACTION AND REACTION

The force exerted by one body upon another is sometimes referred to as the "Action" of the body; e.g. a book, of weight 2 lb., has an "*action*" of 2 lb. on the table on which it rests. The table, however, reacts with an equal force upon the book, the "*Reaction*" of the table holding it still by counteracting the pull of gravity.

Action and Reaction are equal and opposite.

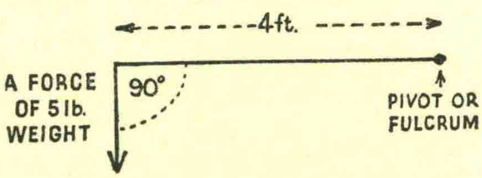


A force may be either a "push" or a "pull". We give the latter a special name —a "Tension".

MOMENTS

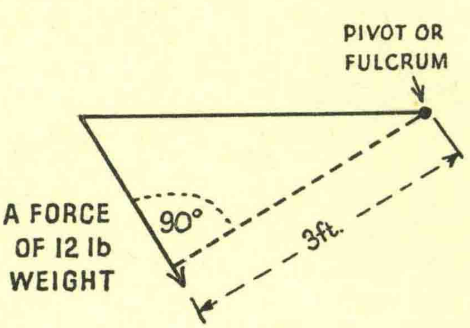
The moment of a force is its turning effect about a particular point. It is measured by multiplying the size of the force by the *perpendicular* distance from the point (i.e. the distance measured at right angles to the force).

Example 1:



The moment = 5 lb. × 4 ft. = 20 lb. ft.

Example 2:

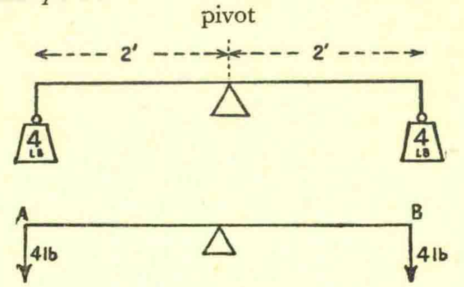


The moment = 12 lb. × 3 ft. = 36 lb. ft.

Moments can be "clockwise" ↻ or "anticlockwise" ↺.

Several forces may act upon one body at the same time and yet the body may stay still or "be in equilibrium". In this case the sum of the clockwise moments must equal the sum of the anticlockwise moments.

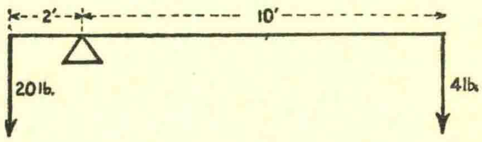
Example 1:



A causes the beam to swing in the direction opposite to that of the hands of a clock ∴ it has an anticlockwise moment of 4 lb. × 2 ft. = 8 lb. ft.

B has a clockwise moment of 4 lb. × 2 ft. = 8 lb. ft. ∴ the beam is in equilibrium—balanced.

Example 2:

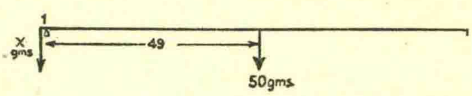


Clockwise moment = 4 lb. × 10 ft.
= 40 lb. ft.

Anticlockwise moment = 20 lb. × 2 ft.
= 40 lb. ft.

∴ equilibrium

Example 3: A 100 cm. rule has a hole drilled 1 cm. from the end and is hung up with string. It weighs 50 gm. What weight must be hung on the end to make it balance?



The weight of the rule is reckoned as acting at its middle.

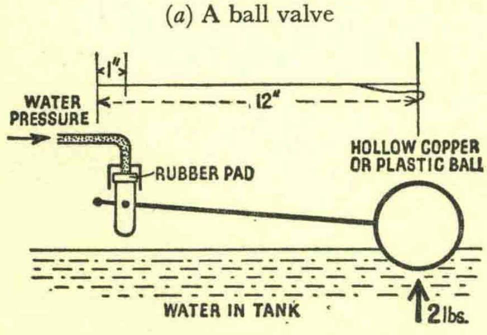
Clockwise moment = 50 gm. × 49 cm. = 2,450 gm. cm.

Anticlockwise moment = x gm. × 1 cm. = x gm. cm.

For balance, x = 2,450 gm.

Useful applications of the Law of Moments

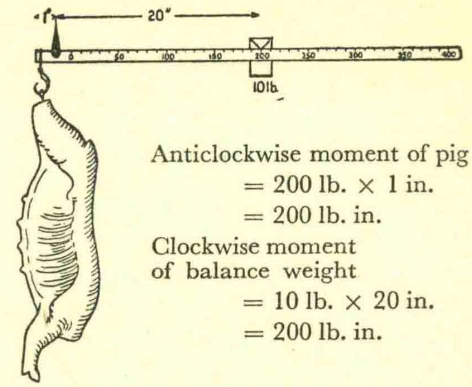
(*a*) A ball valve



The water lifts the ball upward with a force of 2 lb. The force on the rubber pad holding back the water supply is

$$\frac{12}{1} \times 2 \text{ lb.} = 24 \text{ lb.}$$

(*b*) The steelyard



Anticlockwise moment of pig
= 200 lb. × 1 in.
= 200 lb. in.

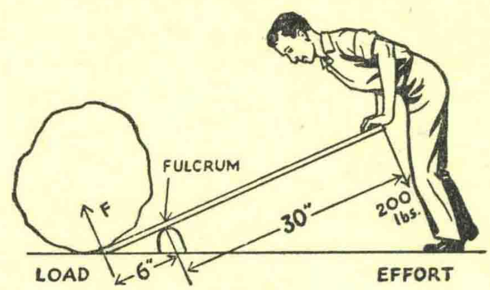
Clockwise moment of balance weight
= 10 lb. × 20 in.
= 200 lb. in.

The pig is weighed by sliding a small steel weight along the steelyard, instead of using massive iron weights.

LEVERS

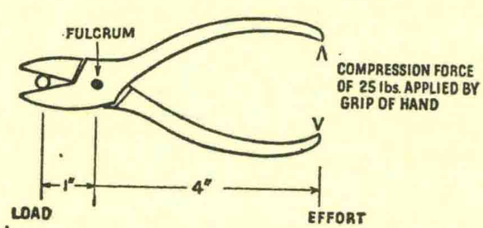
LEVERS OF THE FIRST ORDER

Fulcrum between load and effort.



F × 6 = 200 × 30
F = 1,000

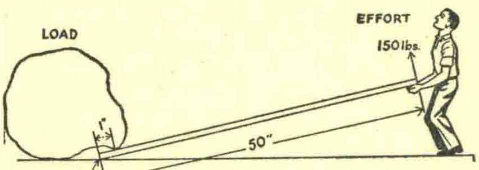
By means of this crowbar, the man, by exerting a force of 200 lb., is able to apply a force of 1,000 lb. to shift the stone.



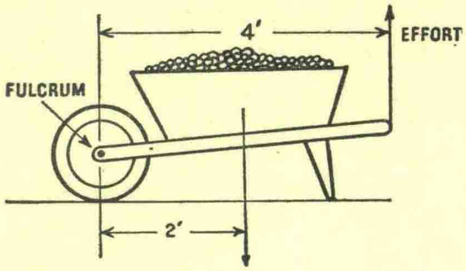
Force applied to wire by cutting edge of the pliers is 25 lb. × $\frac{4 \text{ in.}}{1 \text{ in.}}$ = 100 lb.

LEVERS OF THE SECOND ORDER

Fulcrum at one end and effort at the other.



Force applied to rock = 150 lb. × $\frac{50}{1}$
= 7,500 lb.



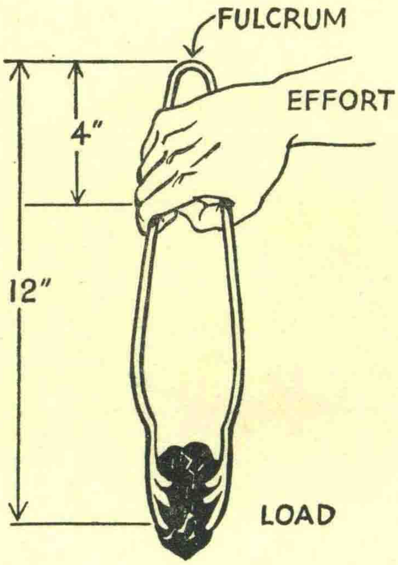
Load = 200 lb.
Reckoned to act at centre.

$200 \times 2 = \text{Effort} \times 4.$

$$\therefore \text{Effort} = \frac{200 \times 2}{4} = 100 \text{ lb.}$$

LEVERS OF THE THIRD ORDER

Fulcrum and the load at the ends.



Grip of hand = a force of 15 lb.

Grip of claws on coal $= \frac{4}{12} \times 15$ lb.

= 5 lb.

Note that in this case the load is *less* than the effort.

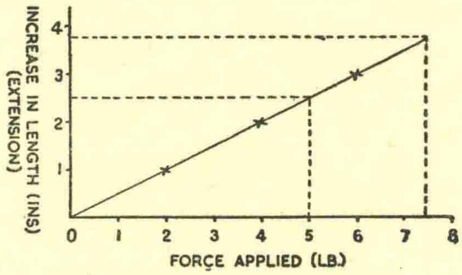
THE ACTION OF SPRINGS

HOOKE'S LAW. The extension of a spring is directly proportional to the force applied to it.

Example: A pull of 2 lb. extends a certain spring by 1 in., 4 lb. by 2 in., 6 lb. by 3 in. and so on. The force applied is often called the "stress", and the "give" of the spring the "strain". A more general way of stating Hooke's Law is, *strain is directly proportional to stress.*

Note: Hooke's Law is only true up to a certain point, known as the "elastic limit" of the material. When a force is applied to a spring and gradually increased, the extension of the spring goes up steadily with the increasing force. If the load is removed, the spring flies back at once to its original length.

A point is reached, however, when a slight increase in the load produces a very large increase in length, and the spring does not fly back when the load is removed. The spring has passed its "*elastic limit*", and is now useless.

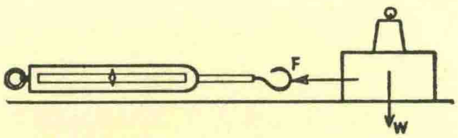


A graph illustrating Hooke's Law

Note: (1) A pull of 5 lb. stretches the string $2\frac{1}{2}$ in.

(2) When the spring is extended by $3\frac{3}{4}$ in., the force is $7\frac{1}{2}$ lb.

FRICTIONAL FORCES



The spring balance is used to pull the wood block across the table, the necessary effort being read from the spring balance.

Results:

(1) Much force must be applied before the body moves. This force is equal and opposite to the *frictional force* between the block and the table, which adjusts itself just to equal the pull applied.

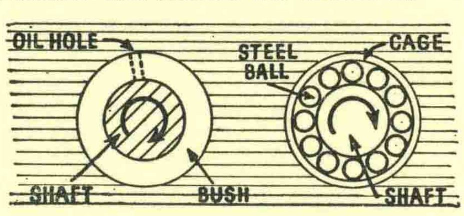
(2) A maximum reading of the balance is reached, at which the block moves steadily across the table. This is the *limiting friction* (F).

(3) The greater the weight applied to the block, the greater is the *limiting friction* (F).

(4) If F is divided by the total force between the two surfaces (W in this case), $\frac{F}{W}$ is always the same for the same surfaces.

$\frac{F}{W}$ = *coefficient of limiting friction.*

(5) Different surfaces have different coefficients of limiting friction. Oil smooths a surface and reduces the coefficient.

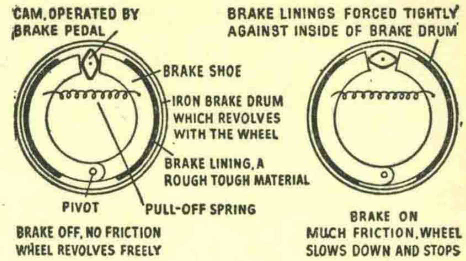


A plain bearing — A ball bearing

A shaft revolves in a bush of a highly polished metal, say bronze. Oil reaches the surfaces through a hole in the bush.

A shaft is supported by highly polished steel balls, contained in a cage. Ball bearings often run in a bath of oil.

A case in which friction is reduced to the minimum.



A case in which friction is increased to the maximum.

Calculation: It needs a horizontal force of 50 lb. to move a box weighing 112 lb. across a tiled floor. What force should be required to push back the empty box weighing 14 lb.?

(Case 1) Coefficient of limiting friction $= \frac{50}{112}$

(Case 2) Coefficient of limiting friction $= \frac{P}{14}$

$$\therefore \frac{50}{112} = \frac{P}{14}$$

$$\therefore P = \frac{50 \times \cancelto{1}{14}}{\cancelto{8}{112}} = \frac{50}{8} = 6{\cdot}25 \text{ lb.}$$

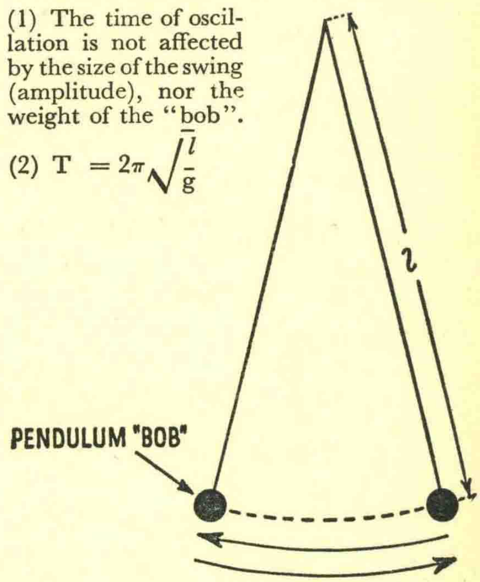
THE PENDULUM

The pendulum consists of a heavy weight supported by a light string or rod. This is another example of stable equilibrium.

THE LAWS OF THE PENDULUM

(1) The time of oscillation is not affected by the size of the swing (amplitude), nor the weight of the "bob".

(2) $T = 2\pi\sqrt{\frac{l}{g}}$



If T is in seconds, l in feet, g = 32.

T = time to complete a whole swing, i.e. *there and back.*

Example 1: A pendulum is 2 feet long. What is its time of oscillation, (T)?

$$T = 2\pi\sqrt{\frac{2}{32}} = 2\pi\sqrt{\frac{1}{16}} = 2\pi \times \frac{1}{4}$$

$$= \frac{\pi}{2} = \frac{22}{7 \times 2} = \frac{11}{7}$$

Time = $1\frac{4}{7}$ seconds.

Example 2: A grandfather clock has a pendulum which swings from one side to the other in 1 second. What is its length?

$T = 2$ seconds. $T = 2\pi\sqrt{\frac{l}{32}}$

$2 = \frac{2 \times 22}{7}\sqrt{\frac{l}{32}} \quad \therefore \frac{7}{44} \times 2 = \sqrt{\frac{l}{32}}$

$\therefore \frac{7}{22} = \sqrt{\frac{l}{32}}$

$\therefore \frac{7^2}{22^2} = \left(\sqrt{\frac{l}{32}}\right)^2 = \frac{l}{32}$

$\therefore \frac{49}{484} = \frac{l}{32}$

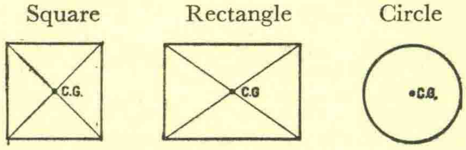
$\therefore l = \frac{49 \times \cancelto{8}{32}}{\cancelto{121}{484}} = 3{\cdot}24$ ft. $= 3$ ft. 3 in. approx.

CENTRE OF GRAVITY

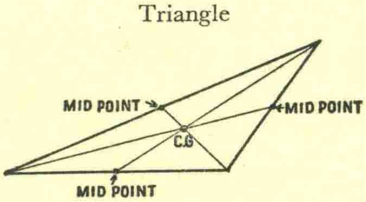
Although the weight is, in fact, distributed all over an object, it is convenient to consider that it is concentrated at one point, the *centre of gravity*. For regularly distributed weight (e.g. a rectangular block, a solid ball) the C.G. is at the centre. If it is possible to support a body at its C.G. (e.g. on a needle point) it will balance. When suspended on a string, the C.G. of the body is always vertically under the support.

Thin objects—e.g. sheet metal or cardboard shapes.

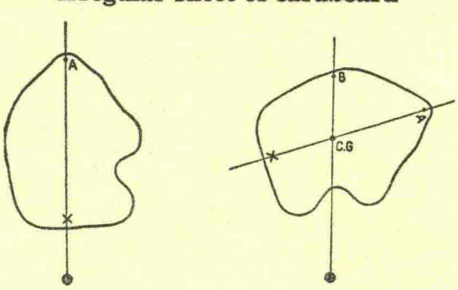
Square Rectangle Circle



Triangle



Experiment to find the C.G. of an irregular sheet of cardboard



Stage 1. Suspend by string from any point A, with plumb-line (vertical) in front. Mark position of plumb-line AX.

Stage 2. Suspend from any other point B. C.G. is where plumb-line crosses line AX, already marked in.

STABILITY

STABLE EQUILIBRIUM

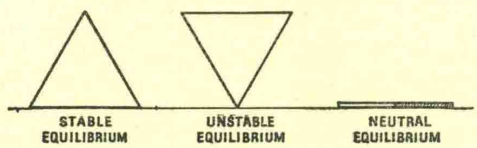
A chair is in stable equilibrium because when it is tilted a little, and released, it moves back to the previous position.

UNSTABLE EQUILIBRIUM

A pencil balanced upon its point is in unstable equilibrium because a slight movement one way results in a much larger one in the same direction.

NEUTRAL EQUILIBRIUM

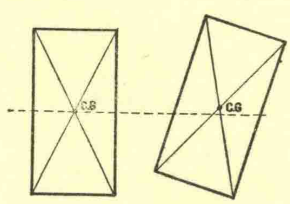
A billiard ball on a horizontal table is in neutral equilibrium, since, after a slight movement, it neither goes back nor goes further.



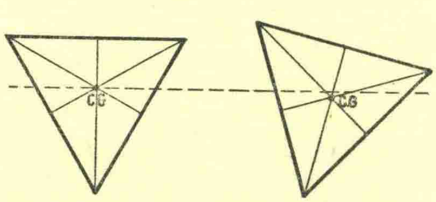
A demonstration of equilibrium with a plywood triangle

RELATIONSHIP BETWEEN CENTRE OF GRAVITY AND STABILITY

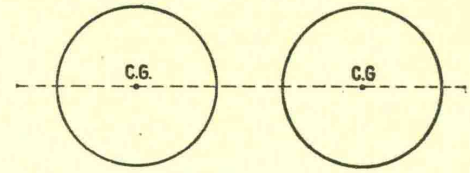
When a body is tilted, the position of the C.G. is changed. If it rises vertically, there is stable equilibrium. If it falls vertically, there is unstable equilibrium.



C.G. of tilted body is higher than before. ∴ it drops on release, restoring body to original position. ∴ *stable equilibrium.*

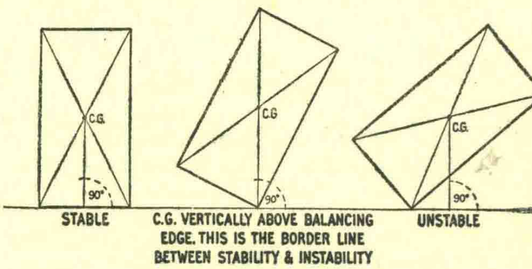


C.G. of tilted body is lower than before. ∴ when it drops still further, on release, the movement is in the same direction. ∴ *unstable equilibrium.*

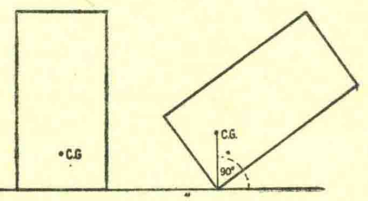


C.G. neither raised nor lowered by moving billiard ball. ∴ *neutral equilibrium.*

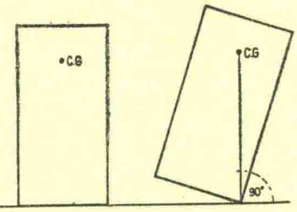
The C.G. of a body in stable equilibrium is vertically over the base



A low C.G. makes for stability.

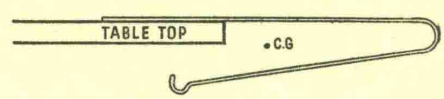


(1) *Heavy weights kept to bottom of structure, giving low C.G.* The body has to tilt a very great distance before it becomes unstable.

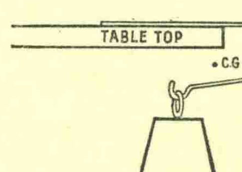


(2) *Heavy weights concentrated near top of structure, giving high C.G.* The body needs very little tilt before it becomes unstable.

An interesting example of stability.



(1) This hook, made of stiff wire, falls off as soon as it is released. The C.G. is not vertically below the supporting body.
(2) The same hook, carrying a heavy weight, no longer falls when released.



The C.G. of the combined weight and hook is near to the weight, and under the

table which is supporting the hook. The hook no longer topples, although it carries much more weight than before.

> EXAMPLES OF LOW CENTRE OF GRAVITY FOR SAFETY
> (1) A racing car is built low to the ground.
> (2) Passengers are not allowed to stand on top of a bus.
> (3) It is foolish for several people in a rowing boat to stand up at the same time.

MACHINES

A machine is a contrivance for overcoming a resistance at one point by the application of a force at another. The force applied (P) is known as the *Effort*. The resistance overcome (L) is the *Load*.

The lever is a very simple type of machine.

The Mechanical Advantage of a Machine (M.A.)

$$= \frac{\text{Load}}{\text{Effort}} = \frac{L}{P}$$

Note: This depends very much upon the condition of the machine, lubrication, etc.

The Velocity Ratio of a Machine (V.R.)

$$= \frac{\text{distance moved by Effort}}{\text{distance moved by Load}}$$

Note: This depends entirely on the geometry of the machine—a well-kept and lubricated machine has exactly the same velocity ratio as one neglected, rusted and stiff.

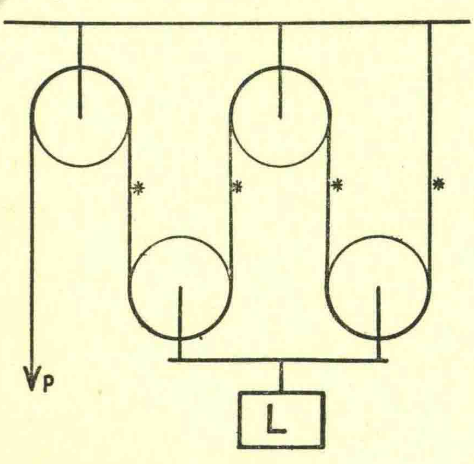
The Efficiency of a Machine

$$= \frac{\text{Energy obtained from machine}}{\text{Energy supplied to machine}}$$

$$= \frac{\text{Mechanical advantage}}{\text{Velocity ratio}}$$

N.B.: Efficiency can never exceed 1, or 100%.

Example 1: **A pulley system.**



Effort = Pull on rope (P).
Load = Weight to be raised (L).

To find velocity ratio. Suppose L to be lifted vertically upward 1 ft. There will be 1 ft. of slack in each of the ropes marked *; to pull up the slack, P must move 4 ft.

$$\therefore \text{ Velocity ratio} = \frac{4}{1} = 4.$$

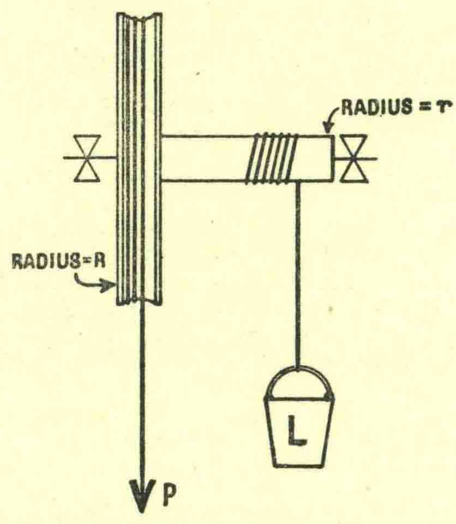
Suppose L = 100 lb. and P = 40 lb.

$$\text{Mechanical advantage} = \frac{L}{P} = \frac{100}{40} = \frac{10}{4}$$

$$= 2{\cdot}5.$$

$$\text{Efficiency} = \frac{\text{M.A.}}{\text{V.R.}} = \frac{2{\cdot}5}{4} = {\cdot}625 \text{ or } 62{\cdot}5\%.$$

Example 2: **A wheel and axle.**



Consider one complete turn of the wheel and axle. The wheel will wind off a length of rope equal to its circumference, $2\pi R$. $\therefore$ P moves $2\pi R$.

The axle will wind up a length of rope equal to its circumference, $2\pi r$ $\therefore$ L moves $2\pi r$

$$\therefore \text{ V.R.} = \frac{2\pi R}{2\pi r} = \frac{R}{r}.$$

Suppose R = 20 and r = 4

$$\therefore \text{ V.R.} = \frac{20}{4} = 5.$$

Suppose L = 50 lb. and P = 20 lb.

$$\text{Mechanical advantage} = \frac{50}{20} = 2{\cdot}5.$$

$$\text{Efficiency} = \frac{\text{Mechanical advantage}}{\text{Velocity ratio}} = \frac{2{\cdot}5}{5}$$

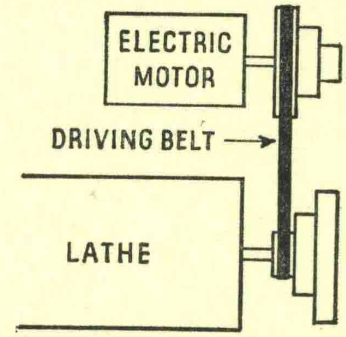
$$= {\cdot}5$$

$$= 50\%.$$

Note: Although, in general, high efficiencies are aimed at, because less energy is wasted in working the machine, an efficiency of less than 50% is sometimes regarded as an advantage in a particular case. Consider, for example, a pulley system, which is highly efficient. Immediately the hands are taken from the rope, the load being raised takes control, begins to fall and causes the pulleys to run in the reverse direction. If the efficiency is less than 50% the weight itself cannot exert enough force to work the machine, so it hangs stationary when the operator releases the rope on which he is pulling.

Example 3: **A machine with a variable velocity ratio.**

A belt-driven lathe.



Suppose the radii of the pulleys are 2 in., 3 in. and 4 in. With the belt as shown, the velocity ratio is $\frac{2}{4} = \frac{1}{2}$.

With the belt in the middle position, the velocity ratio is $\frac{3}{3} = 1$.

In the outside position, the V.R. = $\frac{4}{2} = 2$.

The same idea is used (with a different method of achieving it) in the gear-box of a motor car, which usually has three or four different ratios, plus one extra, for going backwards.

Example 4: **Chain-wheels and sprockets on a cycle.**

The chain-wheel is turned by the pedals, pulling round with it an endless chain which passes over the rear sprocket which in turn drives the rear wheel.

Chain-wheels can be bought with from 40 to 54 teeth, and sprockets with from 14 to 22.

For very high speeds on a level racing track, a very powerful rider might choose a 14-tooth sprocket and a 54-tooth chain-wheel.

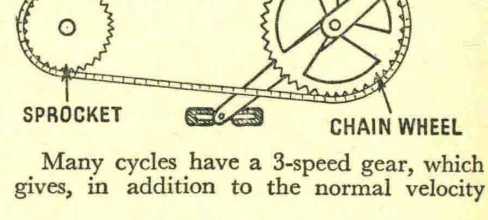
$$\text{Velocity ratio} = \frac{14}{54} = \frac{1}{3{\cdot}9}$$

(the back wheel goes round almost four times as fast as the pedals).

For a young child or invalid, we might go to the other extreme, a 22-tooth sprocket driven by a 40-tooth chain-wheel.

$$\text{V.R.} = \frac{22}{40} = \frac{1}{1{\cdot}8}$$

This will be a very slow bicycle, but will be easy to propel.

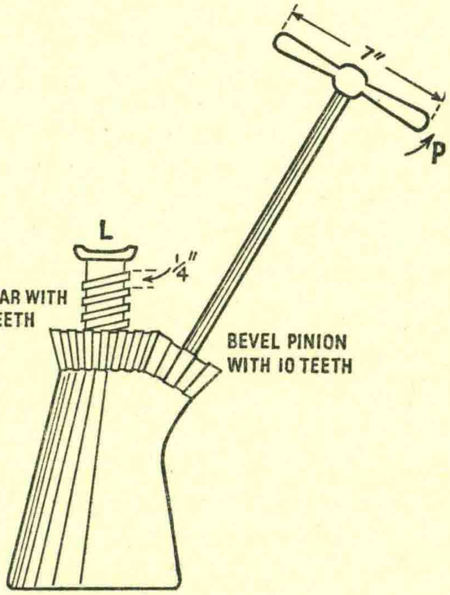


Many cycles have a 3-speed gear, which gives, in addition to the normal velocity

ratio, a specially high one ("low gear") for climbing hills, and a specially low one ("high gear") for going fast on the level or downhill.

The three-speed hub commonly employed multiplies the normal velocity ratio by $\frac{4}{3}$ for low gear and divides it by $\frac{4}{3}$ for high gear.

Example 5: **A car-jack—a screw-jack.**



Let the hands turn the handle through one complete revolution. Assuming hands are pressing on the ends of the handle, distance moved by effort = $\pi \times$ diameter $= \frac{22}{7} \times 7$ in. = 22 in.

The bevel pinion makes one complete revolution too, its 10 teeth passing through 10 of the 40 teeth of the collar and so turning it $\frac{10}{40}$ turns = $\frac{1}{4}$ turn.

When the collar makes one complete turn it lifts the load by the "pitch" of the screw, $\frac{1}{4}$ in. In $\frac{1}{4}$ turn, it lifts it $\frac{1}{4}$ of $\frac{1}{4}$ in. = $\frac{1}{16}$ in.

Velocity ratio = 22 in. $\div \frac{1}{16}$ in. = 22×16
= 352.

It is found that a force of 8 lb. applied to the end of the handle of the jack will raise a load of 1,056 lb. The Mechanical Advantage $= \frac{1{,}056}{8} = 132$.

$$\therefore \text{Efficiency} = \frac{\text{M.A.}}{\text{V.R.}} = \frac{132}{352} = \frac{3}{8} = 37{\cdot}5\%$$

WORK

Work done by a force = force exerted $\times$ distance moved in the direction of the force.

Example 1: A 7-lb. weight is lifted from the floor on to a table 3 ft. high. How much work has been done?

Work = Force $\times$ Distance = P $\times$ S
= 7 lb. $\times$ 3 ft. = 21 ft.-lb.

Example 2: A 15-stone man climbs a flight of stairs to a room 40 ft. above ground level. How much work does he do?

15 stone = 15×14 = 210 lb.

Work = P $\times$ S = 210×40 = 8,400 ft.-lb.

(Calculations such as this explain why heavy people with heart trouble are advised to sleep downstairs.)

Example 3: A locomotive, exerting a force of 1,000 lb., pulls a train 1 mile along a level track. How much work has been done?

Work = P $\times$ S = 1,000 lb. $\times$ 5,280 ft.
= 5,280,000 ft.-lb.

The unit of work is the foot-pound—the work done when a force of 1 lb. weight moves 1 ft. in the direction of the force.

There is another unit, the erg, which is the work done when a force of 1 dyne (1 gm. wt. $\div$ 981) moves 1 centimetre in the direction of the force.

POWER

Power is the rate at which work is done. E.g. if 1,000 ft.-lb. of work are done in 4 sec., the power of the machine is 250 foot-pounds per second.

1 Horse-power = 550 ft.-lb. per second.

Example: A car engine is developing 20 horse-power and is driving the car at 30 m.p.h. What force is being applied to the road to propel the car?

20 horse-power = 20 $\times$ 550 ft.-lb. per sec.
= 11,000 ft.-lb. per sec.

30 m.p.h. = 44 ft. per sec.

In 1 second, force P moves 44 ft. and does 11,000 ft.-lb. of work.

Work = P $\times$ S

$\therefore$ 11,000 = P $\times$ 44

$$\therefore P = \frac{11{,}000}{44} = \frac{1{,}000}{4} = 250.$$

The force is 250 lb.

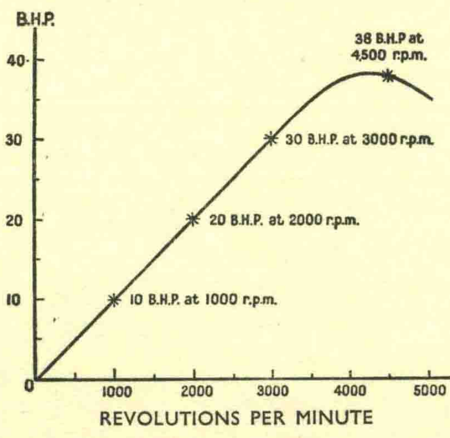
BRAKE HORSE-POWER (B.H.P.)

Brake horse-power is the actual power output of the engine. The name is derived from one method of measuring power, in which the engine is made to drive a wheel against a measured braking force.

INDICATED HORSE-POWER (I.H.P.)

This is a horse-power calculated for a machine from a knowledge of its design and size, as well as the energy it receives in the form of fuel. It is always very much greater than the B.H.P. because even the best engines waste most of the energy given to them, giving out large quantities of unwanted heat. (Hence the need for a car radiator.)

$$\text{Efficiency of an engine} = \frac{\text{B.H.P.}}{\text{I.H.P.}}$$



The B.H.P. graph of a car engine (a so-called 10-h.p. car)

Note how it is necessary to keep the engine running fast in order to develop maximum power—hence the need for a variable gear-box. Also, the graph explains why it is so easy for an inexperienced driver to stop his engine when starting from a standstill. There is hardly any power when the engine is running slowly.

ELECTRICAL UNITS OF POWER

The electrical units of power are the watt and the kilowatt.

1 **horse-power** is equivalent to 746 watts or ·746 kilowatts.

Example 1: An electric motor has an efficiency of 95% and requires a power of 3 kilowatts. What horse-power will it deliver?

3 kilowatts = 3,000 watts.

Efficiency = 95%. $\therefore$ output = 95% of 3,000 watts = 2,850 watts.

But 746 watts are equivalent to 1 horse-power, $\therefore$ 2,850 watts are equivalent to $\frac{2{,}850}{746}$ h.p. = 3·8 h.p.

Example 2: An electric motor is employed to drive a machine needing a power of 2 h.p. If the motor is 80% efficient, what electrical power will it need?

2 h.p. = 2 $\times$ 746 watts = 1,492 watts.

The motor is only 80% efficient, so it will need $\frac{100}{80} \times 1{,}492$ watts to drive it = 1,865 watts.

Example 3: An electric motor delivers 5 horse-power and is driven by 4,103 watts. Calculate its efficiency.

$$\text{Efficiency} = \frac{\text{output power}}{\text{input power}} = \frac{5 \text{ h.p.}}{4{,}103 \text{ watts}}$$
$$= \frac{5 \times 746 \text{ watts}}{4{,}103 \text{ watts}} = \frac{3{,}730}{4{,}103}$$
$$= \frac{10}{11} = 90{\cdot}9\%.$$

THE MECHANICAL EQUIVALENT OF HEAT

778 ft.-lb. of work must be done in order to produce 1 B.Th.U. of heat.

Example: A waterfall is 389 feet high. Assuming that all the energy of the falling water is converted to heat, how would the temperatures of the water at the top and bottom of the waterfall compare?

Consider 1 lb. of water. It moves 389 ft. in the direction of the force of 1 lb. causing it to fall, $\therefore$ work done = P $\times$ S = 1 $\times$ 389 = 389 ft.-lb.

This is equivalent to $\frac{389}{778}$ B.Th.U. = $\frac{1}{2}$ B.Th.U. This quantity of heat raises the temperature of 1 lb. of water through $\frac{1}{2}$°F.

POTENTIAL ENERGY

This is the energy stored in a body by virtue of its position.

Example: To wind a grandfather clock, a weight of 20 lb. is raised through 3 ft. vertically. To do this, 20 lb. × 3 ft. = 60 ft.-lb. of work has to be done. This energy is stored up in the weight and given out, little by little, during the coming week, to drive the clockwork. When the weight reaches the floor, the Potential Energy is nil, so the clock stops.

KINETIC ENERGY

This is the energy a body possesses because of its motion.

$\text{K.E.} = \dfrac{Mv^2}{64}$ where K.E. is in ft.-lb., M is mass in pounds and v is its speed in ft. per sec.

Example 1: What is the effect upon Kinetic Energy: (a) of doubling the mass of the moving body; (b) of making the speed five times as great?

(a) K.E. is proportional to Mass; ∴ when Mass is doubled, so is K.E.
(b) K.E. is proportional to v^2—the square of the speed; ∴ when speed is 5 times, K.E. is 5^2 or 25 times.

Example 2: Calculate the Kinetic Energy of a bullet weighing ·05 lb. and travelling at 1,000 ft. per sec.

$$\text{K.E.} = \frac{Mv^2}{64} = \frac{\cdot 05 \times 1{,}000 \times 1{,}000}{64}$$
$$= 781{\cdot}25 \text{ ft.-lb.}$$

THE RELATIONSHIP BETWEEN POTENTIAL AND KINETIC ENERGY

When a body falls from a height it loses Potential Energy and gains Kinetic Energy. The loss in P.E. is exactly balanced by the gain in K.E., i.e. P.E. + K.E. of a certain body remains constant.

A weight, about to drop, has maximum P.E. and no K.E. At the instant of striking the ground, it has maximum K.E. and no P.E.

Note: When the body strikes the ground, the Kinetic Energy cannot disappear—it is converted into other forms, e.g. heat, sound, or it does mechanical work, like making a crater.

A 10-lb. weight is taken to a height of 144 feet and dropped.
Here is its story before hitting the ground.

Time after dropping	*Height (h)*	*P.E.=M×h*	*Speed*	$KE = \dfrac{Mv^2}{64}$	*P.E.+K.E. ft. lb.*
0 sec.	144 ft.	1,440 ft. lb.	0	0	1,440+0 =1,440
1 sec.	128 ft.	1,280 ft. lb.	32 ft. per sec.	$\dfrac{10\times32\times32}{64}$ =160 ft. lb.	1,280+160 =1,440
2 sec.	80 ft.	800 ft. lb.	64 ft. per sec.	$\dfrac{10\times64\times64}{64}$ =640 ft. lb.	800+640 =1,440
3 sec.	0 ft.	0 ft. lb.	96 ft. per sec.	$\dfrac{10\times96\times96}{64}$ =1,440 ft. lb.	0+1,440 =1,440

MOVEMENT

SPEED

Speed or Velocity is the rate of change of position. If a body changes its position rapidly it has a large speed. Units: miles per hour, feet per sec., cm. per sec.

ACCELERATION

Acceleration is the rate of change of velocity.

Example: A car changes its speed from 30 m.p.h. to 60 m.p.h. in 2 minutes.

$$\text{Acceleration} = \frac{60 - 30 \text{ m.p.h.}}{2 \text{ minutes}} = \frac{30 \text{ m.p.h.}}{2 \text{ min.}}$$
$$= 15 \text{ miles per hour per min.}$$

Units: Miles per hour per hour; feet per sec. per sec.; cm. per sec. per sec.

Note: When a body slows down, it has a negative acceleration; e.g. −5 ft. per sec. per sec.

RETARDATION

Retardation is negative acceleration; e.g. an acceleration of − 5 ft. per sec. per sec. is a retardation of + 5 ft. per sec. per sec.

Formulae: u = initial velocity
v = final velocity
a = acceleration
S = distance covered
t = time taken.

Units: All units must "match"; e.g.
u and v in miles per hour
a in miles per hour per hour
S in miles
t in hours

It is assumed that the acceleration is constant.

Equation 1: $\mathbf{S = \text{average speed} \times t}$
$$= \frac{u + v}{2} \times t.$$

Equation 2: $\mathbf{v = u + at.}$

Equation 3: $\mathbf{S = ut + \tfrac{1}{2}at^2.}$

Equation 4: $\mathbf{v^2 = u^2 + 2aS.}$

Note: It is useful to remember that 60 m.p.h. = 88 ft. per sec.

Example (a): A car averaged 95 m.p.h. in a 24-hour road race. How far did it travel?

Eqn. 1: S = average speed × t
= 95 m.p.h. × 24 hours
= 2,280 miles.

Example (b): A car takes 20 seconds to reach 60 m.p.h. from a standing start. Find the acceleration.

Eqn. 2: $v = u + at$
$u = 0$
$v = 60$ m.p.h. $= 88$ ft. per sec.
$t = 20$ secs.
$\therefore 88 = 0 + (a \times 20)$
$\therefore 88 = 20a$
$\therefore a = \dfrac{88}{20} = 4{\cdot}4$

The acceleration is 4·4 ft. per sec. per sec.

Example (c): A goods train has reached the speed of 30 m.p.h. 5½ miles after leaving its starting point. Find the acceleration. u = 0; v = 30 m.p.h. = 44 ft. per sec.; S = 5½ miles.

Eqn. 4: $v^2 = u^2 + 2aS$
$44^2 = 0^2 + 2 \times a \times (5\tfrac{1}{2} \times 5{,}280)$
$44 \times 44 = 0 + 2a \times 29{,}040$

$$a = \frac{\overset{4}{\cancel{44}} \times \overset{4}{\cancel{44}}}{2 \times \underset{\underset{\underset{\underset{15}{\cancel{60}}}{\cancel{240}}}{\cancel{2{,}640}}}{\cancel{29{,}040}}} = \frac{1}{30} \text{ ft. per sec. per sec.}$$

Example (d): A car travelling at 60 m.p.h. on a dry road should be able to stop in 60 yards in an emergency. Calculate the retardation caused by the brakes.

u = 60 m.p.h. = 88 ft. per sec.
v = 0. S = 60 yards = 180 feet.

Eqn. 4: $v^2 = u^2 + 2aS$
$0 = 88^2 + 2 \times a \times 180$
$\therefore -88^2 = 2 \times a \times 180$
$\therefore a = \dfrac{-(88 \times 88)}{2 \times 180}$
$= -21{\cdot}5$ ft. per sec. per sec.

Acceleration = − 21·5 ft. per sec. per sec.
Retardation = 21·5 ft. per sec. per sec.

Example (e): In an acceleration test, a sports car covered a quarter of a mile from a standing start in 20 seconds. Find the average acceleration.

$S = \tfrac{1}{4}$ mile $= \dfrac{5{,}280}{4}$ ft. $= 1{,}320$ ft.

u = 0. t = 20 seconds.

Eqn. 3: $S = ut + \tfrac{1}{2}at^2$
$1{,}320 = (0 \times 20) + (\tfrac{1}{2}a \times 20^2)$
$1{,}320 = 0 + (\tfrac{1}{2} \times 20 \times 20 \times a)$
$1{,}320 = 200a$
$\therefore a = \dfrac{1{,}320}{200} = 6{\cdot}6$

The acceleration is 6·6 ft. per sec. per sec.

THE ACCELERATION DUE TO GRAVITY

A body released above the surface of the earth is subjected to an acceleration, due to gravity, of 32 ft. per sec. per sec., or 981 cm. per sec. per sec. For example:

Time after Release in. secs.	Speed toward Earth	
	ft. per sec.	cm. per sec.
0	0	0
1	32	981
2	64	1,962
3	96	2,943
4	128	3,924
5	160	4,905

This acceleration is referred to as "g". g = 32 ft. per sec. per sec. or 981 cm. per sec. per sec.

Example 1: A stone is dropped from a height. What will be its speed after 10 seconds?
u = 0. t = 10 sec. a = g = 32 ft. per sec. per sec. v = u + at.
v = 0 + (32 × 10) = 0 + 320 = 320 ft. per sec.

Example 2: A stone is shot vertically upward from a catapult with a speed of 90 ft. per sec. What will be its speed 2 seconds later?
u = 90 ft. per sec. (upward)
a = g = 32 ft. per sec. per sec. downward
= − 32 ft. per sec. per sec. upward.
t = 2 seconds.
v = u + at = 90 + (− 32 × 2) = 90 − 64
= 26.
Speed = 26 ft. per sec. upward.

Example 3: What will be the speed of the same stone after 3 seconds?
v = u + at = 90 + (− 32 × 3)
= 90 − 96 = − 6 ft. per sec.
The speed is − 6 ft. per sec. upward, i.e. + 6 ft. per sec. downward.

The stone has already reached its highest point and is on the way down with a speed of 6 ft. per sec.

Example 4: A stone is dropped down a deep well and is seen to splash into the water 5 seconds later. How far below the top of the well is the water level?
u = 0 ft. per sec.
a = g = 32 ft. per sec. per sec.
t = 5 sec.
$S = ut + \frac{1}{2}at^2$
$= (0 \times 5) + (\frac{1}{2} \times 32 \times 5^2)$
$= 0 + (16 \times 25) = 400.$
The distance is 400 feet.

Example 5: A stone is dropped from the edge of a cliff 1,600 feet high. How long does it take to reach the water?
u = 0 ft. per sec.
S = 1,600 ft.
a = g = 32 ft. per sec. per sec.
$S = ut + \frac{1}{2}at^2$
$\therefore 1{,}600 = (0 \times t) + (\frac{1}{2} \times 32 \times t^2)$
$\therefore 1{,}600 = 0 + 16t^2$
$\therefore 100 = t^2$
$\therefore t = 10.$
Time is 10 seconds.

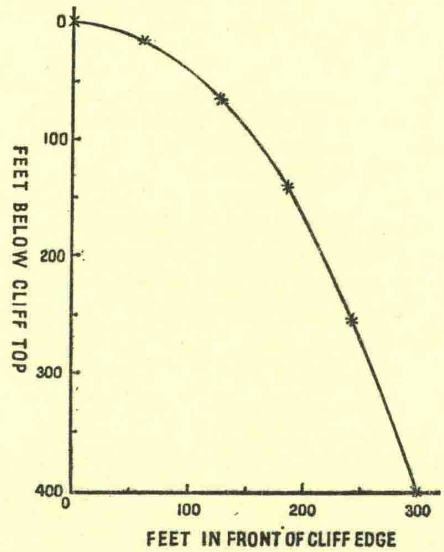
Example 6: A cricket ball is thrown vertically upward with a speed of 96 ft. per sec. How long does it take to reach the highest point?
v = u + at.
Reckon upward as positive.

At turning point ball ceases to rise.
∴ v = 0. u = 96 ft. per sec. a = 32 ft. per sec. per sec.
0 = 96 + (− 32 × t)
∴ 0 = 96 − 32t
∴ 32t = 96 ∴ t = 3.

The ball is 3 seconds on its upward journey.

As a matter of interest, the return journey takes exactly the same time, the speeds on the upward and downward journeys being identical (although opposite in direction) at every point; e.g. 0 ft. per sec. at the extreme altitude and 96 ft. per sec. at the ground. The total time in the air is therefore 6 seconds.

Drawing the path of a stone thrown from a cliff



Take the cliff as 400 feet high, and the horizontal velocity of the stone to be 60 ft. per sec.

Vertical Movement
$S = ut + \frac{1}{2}at^2$
$= (0 \times t) +$
$(\frac{1}{2} \times 32 \times t^2)$
$= 16t^2.$

Horizontal Movement
S = u × t
= 60 × t
= 60t.

Time (sec.)	Vertical drop (feet)
0	0
1	16
2	64
3	144
4	256
5	400
6	576
7	784
8	1,024

Time (sec.)	Horizontal flight (feet)
0	0
1	60
2	120
3	180
4	240
5	300
6	360
7	420
8	480

Drawing the path of an object shot into the air at an angle, e.g. a cricket ball

Note: The object keeps its original velocity unchanged, and receives, in addition, an extra velocity, vertically downward, due to gravity.

Example: A cricket ball hit with a velocity of 80 ft. per sec. at an angle of 45° with the ground.

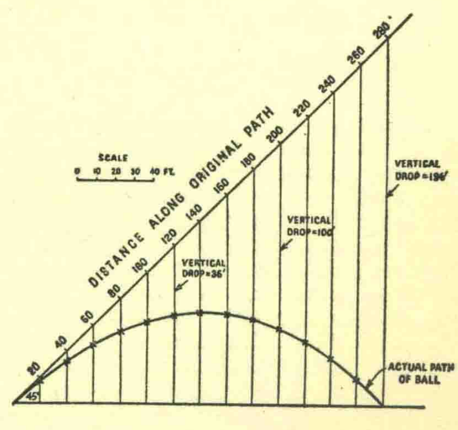
The position of the ball is shown after every ½ second.

Vertical Drop
$S = ut + \frac{1}{2}at^2$
$= (0 \times t) +$
$(\frac{1}{2} \times 32t^2)$
$= 16t^2.$

Movement along original path
S = u × t
= 80t.

Time (sec.)	Vertical drop (feet)
0	0
¼	1
½	4
¾	9
1	16
1¼	25
1½	36
1¾	49
2	64
2¼	81
2½	100
2¾	121
3	144
3¼	169
3½	196
3¾	225
4	256
4¼	289
4½	324
4¾	361
5	400

Time (sec.)	Distance along original path (feet)
0	0
¼	20
½	40
¾	60
1	80
1¼	100
1½	120
1¾	140
2	160
2¼	180
2½	200
2¾	220
3	240
3¼	260
3½	280
3¾	300
4	320
4¼	340
4½	360
4¾	380
5	400



The drawing shows that the ball returns to its original horizontal level 199 feet from where it was thrown. It is in the air for approximately 3½ seconds.

THE EFFECT OF AIR RESISTANCE ON THE RATE OF FALLING UNDER GRAVITY

It is quite true to say that the force of gravity treats all substances alike, and that it gives both to lead shot and to feathers the same downward acceleration of 32 ft. per sec. per sec. Yet experience tells us that lead shot rush to the ground with considerable speed when released, while feathers drift slowly downward. The explanation is the resistance of the air, which has a much greater effect on the large surface of the feather than on the tiny surface of a lead shot of equal weight. Lead shot and feathers do, however, fall at exactly the same rate in the absence of air, i.e. in a vacuum.

According to our velocity equations, the speed of a body dropping from a height increases regularly, reaching a very high value indeed where the height is considerable.

For example:

Time of falling (sec.)	Total distance fallen (feet)	Speed (ft. per sec.)	Speed (m.p.h.)
1	16	32	22
2	64	64	44
3	144	96	65
4	256	128	87
5	400	160	109
6	576	192	131
7	784	224	153
8	1,024	256	175
9	1,296	288	196
10	1,600	320	218
11	1,936	352	240
12	2,304	384	262
13	2,704	416	284
14	3,136	448	305
15	3,600	480	327
20	6,400	640	436
30	14,400	960	655
40	25,600	1,280	873
50	40,000	1,600	1,094

According to these calculations, a man falling from an aeroplane at 40,000 feet would reach the ground in 50 seconds, and strike it with the speed of over 1,000 m.p.h. In practice, due to air resistance, the time is very much longer, and the speed with which he falls is limited to approximately 120 miles per hour. This limiting speed depends upon the weight and the surface area of the body. The larger the surface area, the greater the air resistance and the slower the fall. The surface area of an airman can be made very great indeed by giving him a parachute. With this, his limiting speed may be as low as 12 m.p.h., compared with the speed through air of 120 m.p.h. without a parachute, or of 1,000 m.p.h. or more in a vacuum.

NEWTON'S LAWS OF MOTION (*1686*)

The First Law of Motion. Every body continues in its state of rest or of uniform motion in a straight line unless compelled by the application of a force to change from that state.

The Second Law of Motion. When a body is acted upon by a force, the increase in the acceleration of the body is proportional to the force applied, and takes place in the direction of this force.

The Third Law of Motion. To every Action there is an equal and opposite Reaction.

MOMENTUM

The momentum of a body is a measure of its effect in a collision with other bodies. It is the *product of its mass and velocity*.

If it is assumed that no energy is used up in a collision, e.g. in producing heat or causing damage, then *total momentum of bodies before a collision = total momentum of bodies after collision.*

Example 1: A railway truck weighing 4 tons and moving at 5 m.p.h. collides with a stationary truck weighing 5 tons, and they move on together. Find the speed after collision.

Total momentum before collision
= 4 tons × 5 m.p.h. + 5 tons × 0 m.p.h.

Total momentum after collision
= (4 tons + 5 tons) × V m.p.h.

$$\therefore 20 + 0 = 9 \times V$$

$$\therefore 20 = 9V$$

$$V = 2\tfrac{2}{9} \text{ m.p.h.}$$

Example 2: A bullet weighing 1 ounce is fired with a velocity of 10,000 ft. per second from a rifle weighing 10 lb. Calculate the speed of recoil of the rifle.

First momentum = 0, since no movement.

∴ Total momentum after firing = 0.

$\therefore \frac{1}{16}$ lb. × 10,000 ft. per sec. + 10 lb. × v ft. per sec. = 0.

$$\therefore 10v = -\frac{10{,}000}{16}$$

$$\therefore v = -\frac{1{,}000}{16}$$

$$= -62{\cdot}5$$

The speed of recoil is 62·5 ft. per sec. in the opposite direction to that of the bullet.

THE CONNECTION BETWEEN FORCE AND ACCELERATION

Force is proportional to the acceleration produced. Force is proportional to the mass accelerated—i.e. P is proportional to m and a.

Equation: $P \times g = m \times a$.

Using feet, lb. and seconds as units, $32P = m \times a$.

Using cm., gm. and seconds as units, $981P = m \times a$.

Example 1: What force will be required to give a mass of 2,000 gm. an acceleration of 20 cm. per sec. per sec.?

$$P \times g = m \times a$$

$$P \times 981 = 2{,}000 \times 20$$

$$\therefore P = \frac{40{,}000}{981} = 40{\cdot}8 \text{ gm. approx.}$$

Example 2: A girl weighing 6 stones 12 lb. is in a lift which starts upward with an acceleration of 5 ft. per sec. per sec. How much does she seem to weigh while the lift accelerates?

6 st. 12 lb. = 96 lb.

$$32P = m \times a.$$

$$32 \times P = 96 \times 5$$

$$\therefore P = \frac{96 \times 5}{32} = 15$$

The lift has to push upward on her feet with a force of 15 lb. to give her the required acceleration. There is also a force of 96 lb. due to her weight. She seems to weigh 96 lb. + 15 lb. = 111 lb. = 7 st. 13 lb. while the lift accelerates.

Example 3: A balloon of total weight 6,500 lb. is drifting at a constant altitude. What will be the upward acceleration when 100 lb. of ballast are dropped? (Upward force on balloon is now 100 lb. wt.)

Weight of balloon = 6,500 lb. — 100 lb.
= 6,400 lb.

$$P \times g = m \times a$$

$$\therefore 100 \times 32 = 6{,}400 \times a$$

$$\therefore 3{,}200 = 6{,}400\,a$$

$$\therefore a = \frac{3{,}200}{6{,}400} = \frac{1}{2}$$

The acceleration is ½ ft. per sec. per sec.

Example 4: A car weighing 1 ton is moving with a steady speed of 30 m.p.h. when the brakes are applied, giving a constant retarding force of 1,540 lb. weight. Calculate the retardation produced, and the distance the car moves before coming to rest.

To find retardation:

$$P \times g = m \times a$$

$$\therefore 1{,}540 \times 32 = 2{,}240 \times a$$

$$\therefore a = \frac{32 \times 1{,}540}{2{,}240} = \frac{1{,}540}{70}$$

$$= 22.$$

The retardation is 22 ft. per sec. per sec.

To find distance travelled:

$v^2 = u^2 + 2aS$ (see page 222).

v = 0 (car at rest).

u = 30 m.p.h. = 44 ft. per sec.

a = − 22 (retardation of 22 ft. per sec. per sec.—see above).

S = distance in feet.

$$v^2 = u^2 + 2aS$$

$$0 = 44^2 - 2 \times 22 \times S$$

$$\therefore 2 \times 22 \times S = 44^2$$

$$\therefore 44\,S = 44^2$$

$$\therefore S = \frac{44^2}{44} = 44.$$

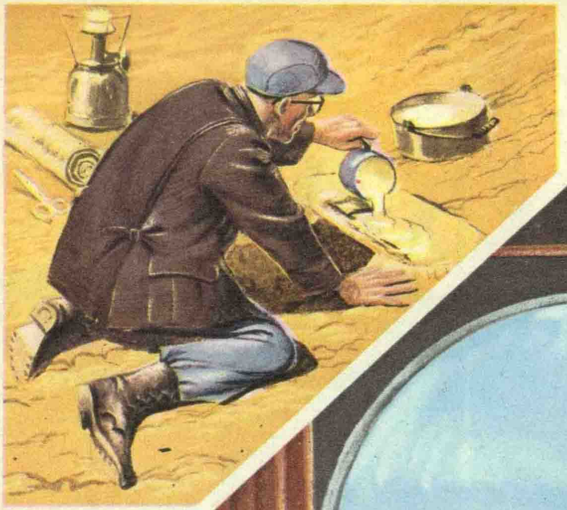
The car will travel 44 feet before stopping.

THE SCIENCE OF ARCHAEOLOGY

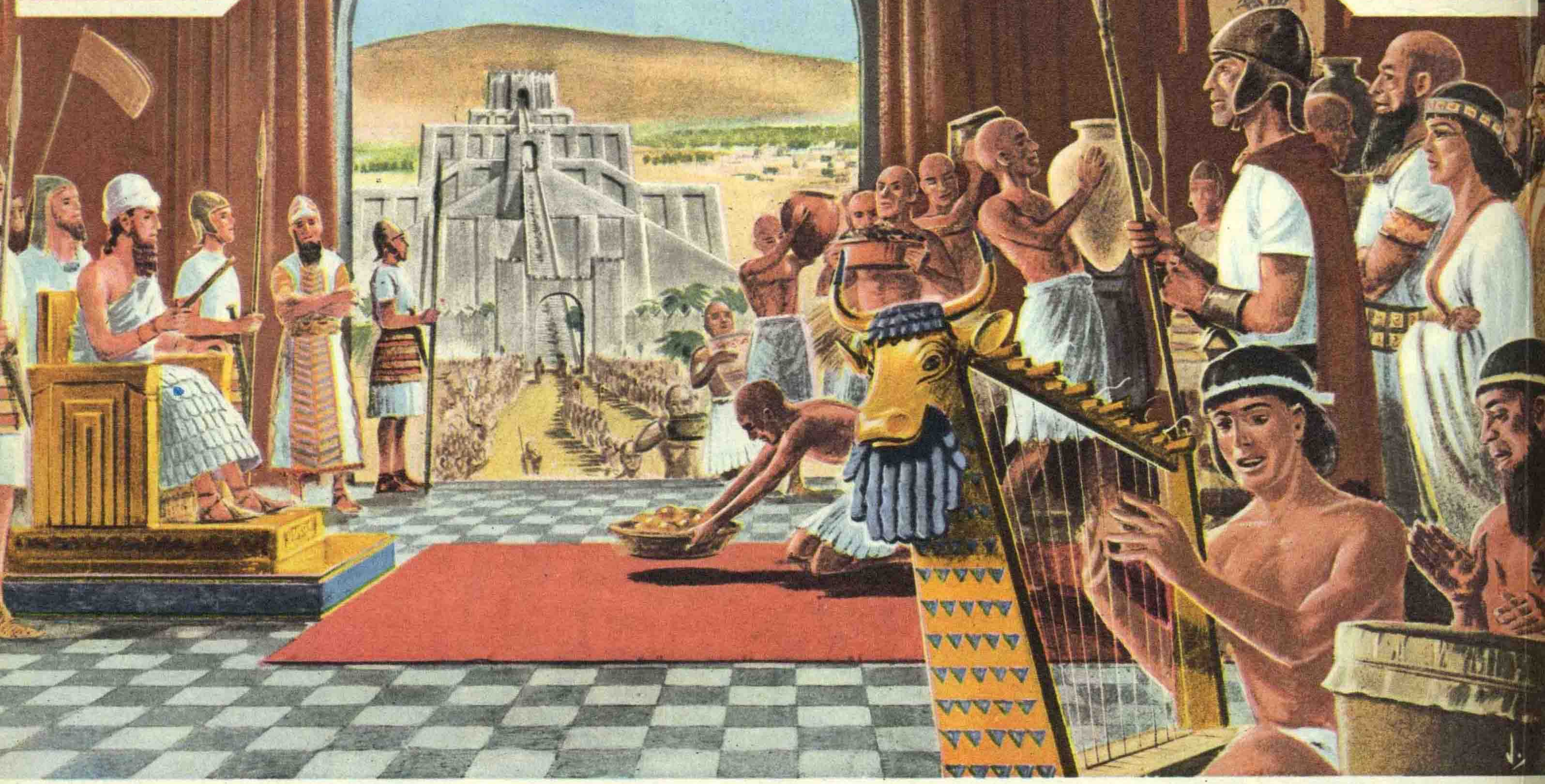
Archaeology is the study of the everyday life of man in ages past. Its scope ranges from the primitive lives of Stone Age cavemen, who left only flints and bones as evidence of their existence, to the advanced culture of the Peruvian Incas, much of whose history is recorded. The aim of archaeologists is to build up as complete a picture as possible by interpreting and piecing together whatever relics and remains may be found. This may involve a lot of careful excavating in the case of an ancient city, buried perhaps beneath drifting sands, or the patient deciphering of ancient manuscripts.

Modern scientific knowledge helps the archaeologist greatly in his work. The picture on this page, for instance, shows how underground photography (where a camera is lowered down a boring to take flashlight pictures) could be used to locate buried tombs.

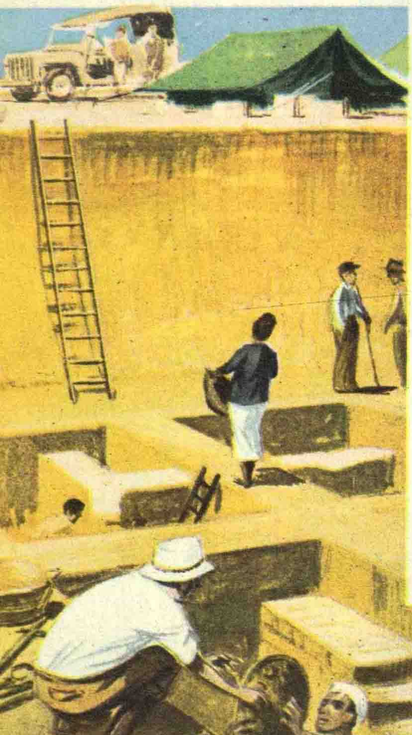
Aerial photography is a great help to archaeologists. The lines of buried settlements have been located by such photographs because grass tends to grow shorter over stone than over deep soil.



A plaster cast (*left*) may be made of a fragile object found during excavations in case of later damage. (*Right*) the age of bones can be found from the amount of fluorine they contain.



The Babylonian civilisation was at its peak during the latter part of the 7th century B.C. But the great Ziggurat was built over 1,500 years previously.



Those lands bordering the Mediterranean Sea, and the Middle East, are of great interest to the archaeologist because it was there that some of the earliest civilisations flourished. Mesopotamia alone has yielded evidence of not one but many successive civilisations having existed there.

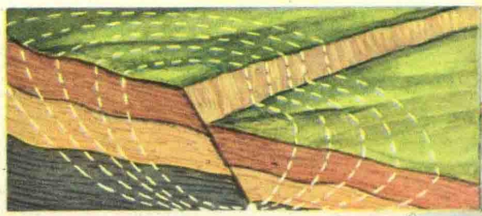
The excavation of an archaeological site is usually carried out in squares (*left*). This makes it possible to record the exact location of any object found and to build up an accurate picture of the whole site. (*Right*) when found, the Dead Sea scrolls, made of bronze, were too crumbly and brittle to be unrolled. A special cutting machine divided them into curved strips which could then be read.

GEOLOGY

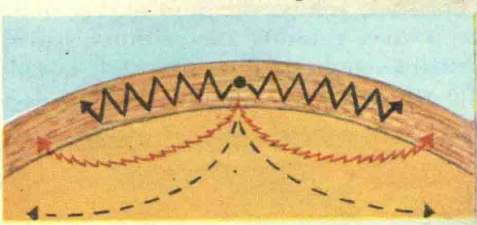
The study of rocks

Geology is the study of the structure of the earth and its surface features. Of the many specialised branches, *petrology*, the study of rocks, and *geomorphology*, the study of land forms and scenery, are the most important.

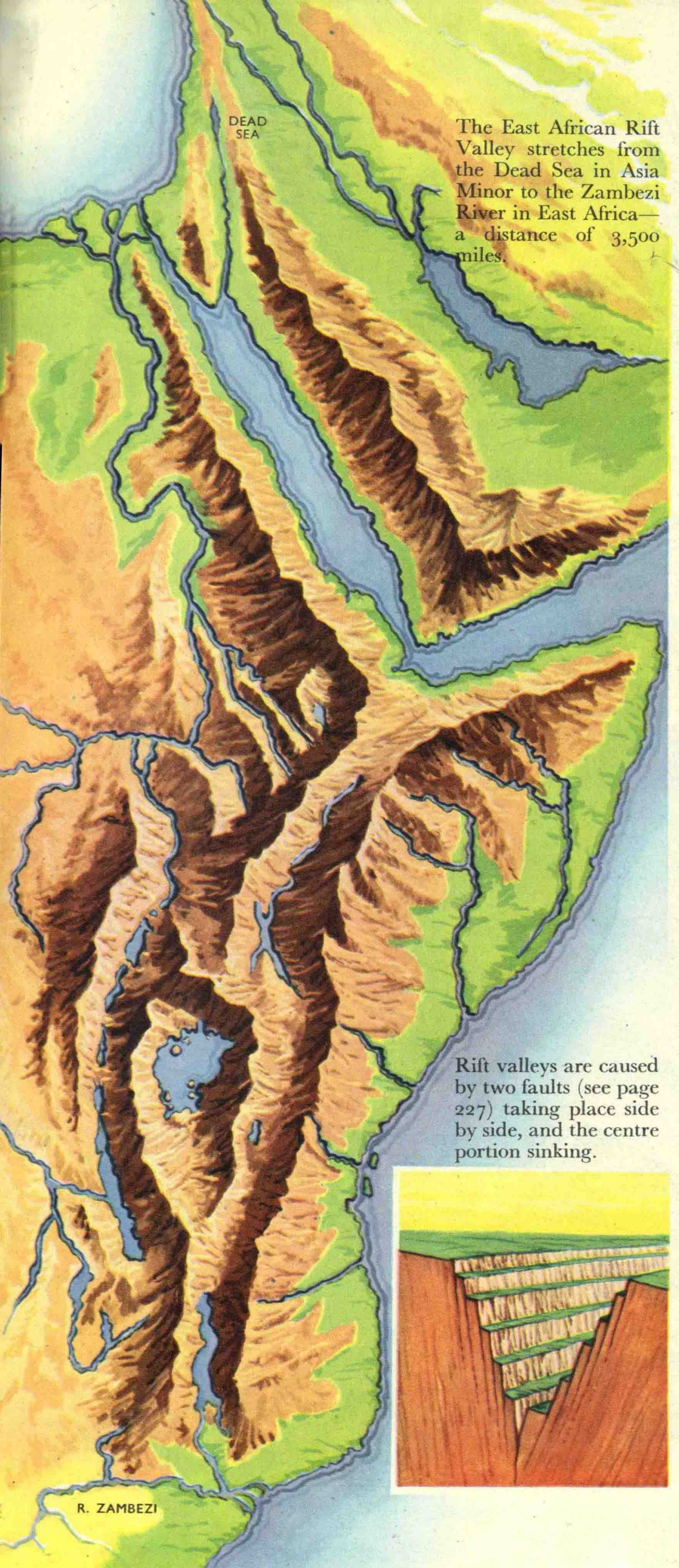
A volcano, the most spectacular land form, is an opening in the earth's crust which acts as a safety-valve for the high pressures of the substratum below. During an eruption, molten rock, ashes, steam and gases are forced through the narrow funnel leading to the crater. If this becomes blocked by cooling lava, the pressure below may increase until the volcano explodes, hurling lumps of molten rock high into the air. The volcanic cone, made up of cooled lava or ash, grows with every eruption until the lava may find it easier to escape through the side.



A *fault* is a breaking of continuous layers of rock through tension in the earth's crust. The vibrations caused by the broken ends rubbing together travel to the surface as earthquake waves.



There are three types of earthquake waves. The fastest, *Primary waves*, vibrate in the direction they are travelling. Like *Secondary waves*, which vibrate in a shaking motion, they travel through the earth's interior. *Long waves*, the slowest, travel only through the earth's crust.



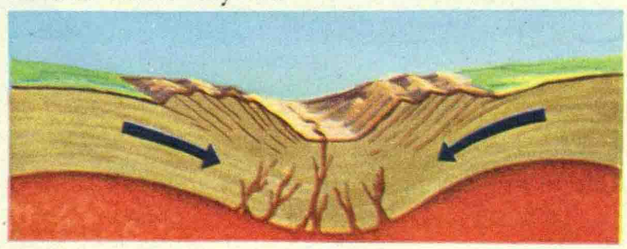
The East African Rift Valley stretches from the Dead Sea in Asia Minor to the Zambezi River in East Africa—a distance of 3,500 miles.

Rift valleys are caused by two faults (see page 227) taking place side by side, and the centre portion sinking.

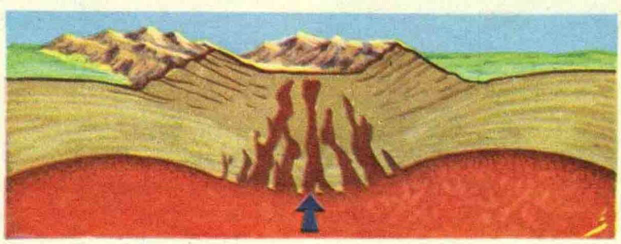
Mountain Building

At various periods in the earth's history, tremendous upheavals in the hot mass of basalt underlying the earth's thin crust have produced great "fold" mountain ranges. The most recent mountain building period—almost 30 million years ago—produced the greatest mountain ranges of today, including the Himalayas, Rockies, Andes and Alps. Although these fold mountains contain the highest points on the earth's surface, the fact that sedimentary rocks (see page 229) may be found at their peaks proves that they were laid down beneath the sea and only later raised to great heights. Such periods, when the earth rumpled its crust into new mountain ranges, are sometimes called "earth storms" despite the fact that each lasted for millions of years.

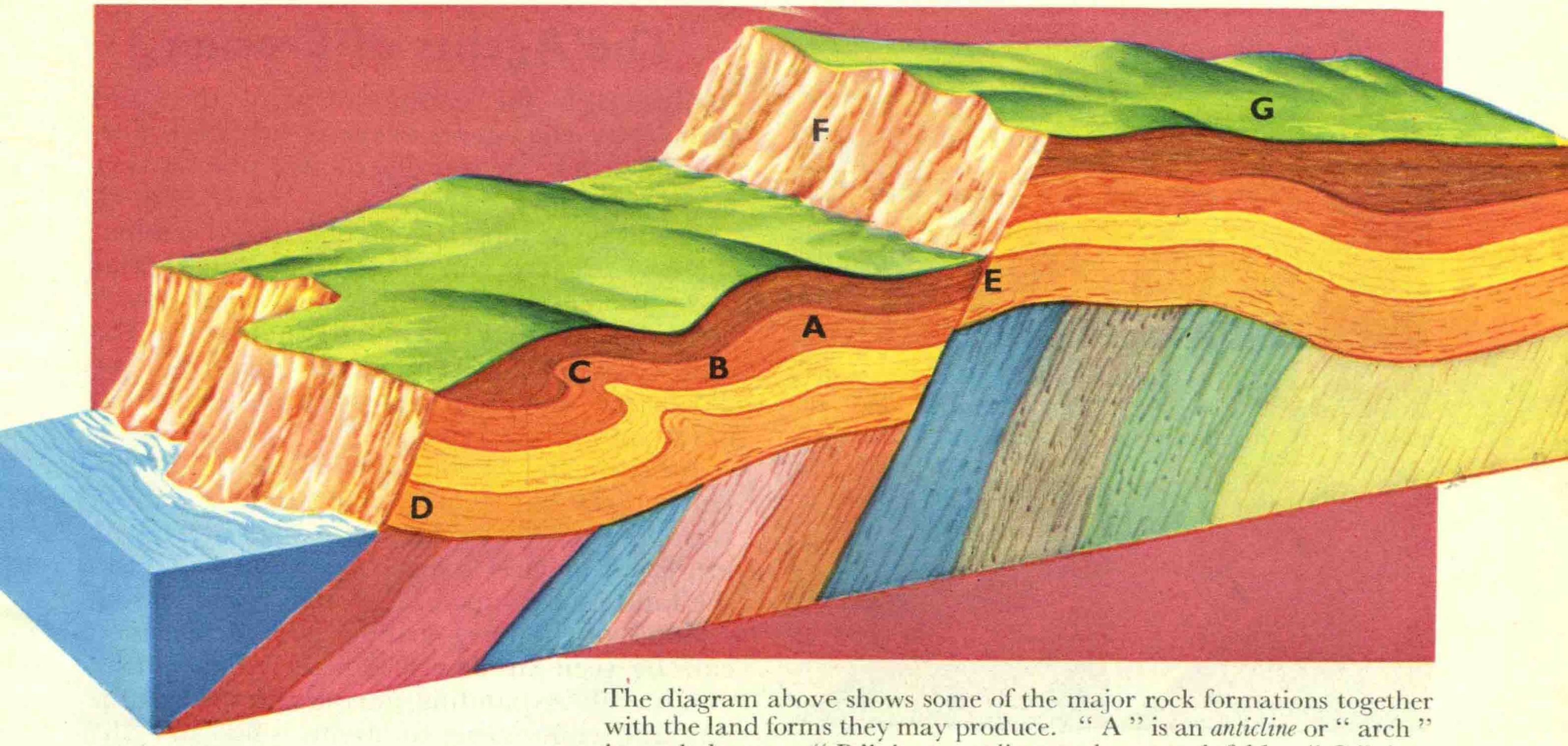
A plateau is an area of land that has been lifted up bodily by pressures in the earth's crust. Plateaux sometimes contain deep valleys caused by faults taking place in the rock layers.



Mountain ranges are laid down in long valleys (called geosynclines) between two stable land masses which are slowly filled with river-borne materials. For some reason the land masses move together like a vice, pushing the sediments deep into the earth's molten interior and simply rumpling the surface.



Then, at a much later date, the whole mass slowly rises to form a mountain range because its rocks (mainly granite) are lighter than those beneath. Finally the mountains rest upon the molten basalt of the earth's interior like icebergs in water with more of their mass below the general level of the land than showing above it.



The diagram above shows some of the major rock formations together with the land forms they may produce. " A " is an *anticline* or " arch " in rock layers. " B " is a *syncline* or downward fold. " C " is a *recumbent fold* caused by great pressure. " D " shows an *unconformity* (new rocks lying at an angle on older ones). The *fault* at " E " produces a steep *scarp slope*—" F " and a gently sloping *dip slope*—" G."

The Formation of Rocks

Rocks are the materials which make up the earth's crust. They may be soft clays, hard granite or flaky chalk. All may be divided into three large groups—igneous rocks, sedimentary rocks and metamorphic rocks.

All igneous rocks are made from rock so hot that it is liquid. Some are formed from lava that flows out of volcanoes, others from magna, liquid rock that lies beneath the earth's crust. This group includes among other rocks basalt and granite.

Sedimentary rocks are made up of fragments of older rocks. Rivers are always carrying pebbles and mud to the sea where they slowly settle in layers. In time, the pebbles and mud are cemented by lime or some other material to form sedimentary rock layers. Limestone and sandstone are two of the best known sedimentary rocks.

If rocks are thrust beneath the earth's surface, as in mountain building (see page 228), the tremendous pressures and heat change them into other rocks. These new rocks are said to be metamorphic (meaning " changed "). Clay, for instance, may be turned into slate or limestone into marble.

Water seeping through the roof of a limestone cave dissolves a little of the rock. Evaporation later produces stalactites (hanging) and stalagmites.

Rocks laid down in layers are said to be *stratified*.

Earth movements can tip rock layers on their side.

The chart below is a classification of rocks according to their age (in millions of years.)

PLEISTOCENE	1
MIOCENE AND PLIOCENE	35
EOCENE AND OLIGOCENE	70
CRETACEOUS	140
JURASSIC	170
TRIASSIC	195
PERMIAN	220
CARBONIFEROUS	275
DEVONIAN	320
SILURIAN	350
ORDOVICIAN	420
CAMBRIAN	520
PRE-CAMBRIAN	—

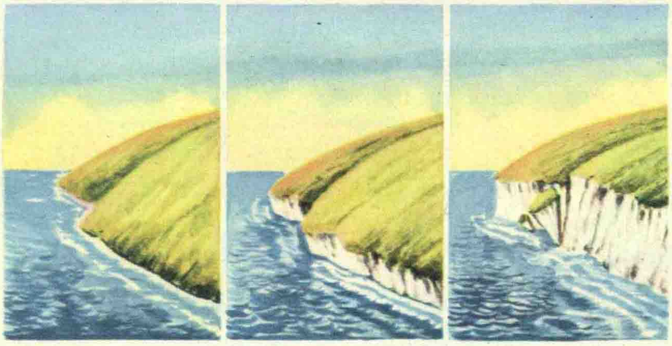
The Agents of Erosion

Erosion is the eating away of the land surface by the agents of the weather—water, ice and wind. It is a destructive process that never stops.

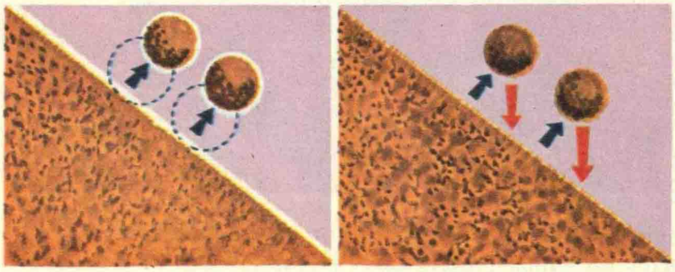
Water is the most spectacular tool of erosion. But the great ocean waves that can shatter rocks and carve out cliffs by their sheer power do nowhere near as much damage as the millions of streams and rivers which day by day carry small soil and rock particles from fields and hillsides to the sea.

Ice can shape the face of the land too. During the Great Ice Age when much of Europe and North America was covered by ice, great glaciers gouged out deep valleys in the land and scraped large areas clear of soil.

Some of the most striking effects of erosion can be seen in desert regions where rocks, continually expanding during the heat of the day and contracting at night, in time, shatter. Some parts split into such small pieces that they become sand. The sharp grains of sand carried along by the wind beat against the rocks, gradually smoothing them off and sometimes producing fantastic shapes.

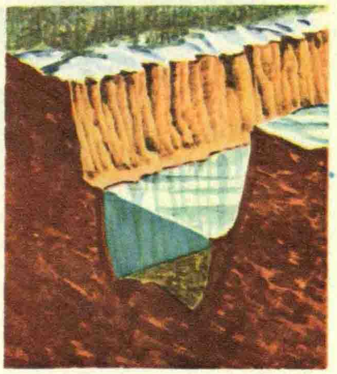


Cliffs are formed by the undercutting action of waves which carve a notch back into the rock until the material above collapses, exposing a bare rock face.



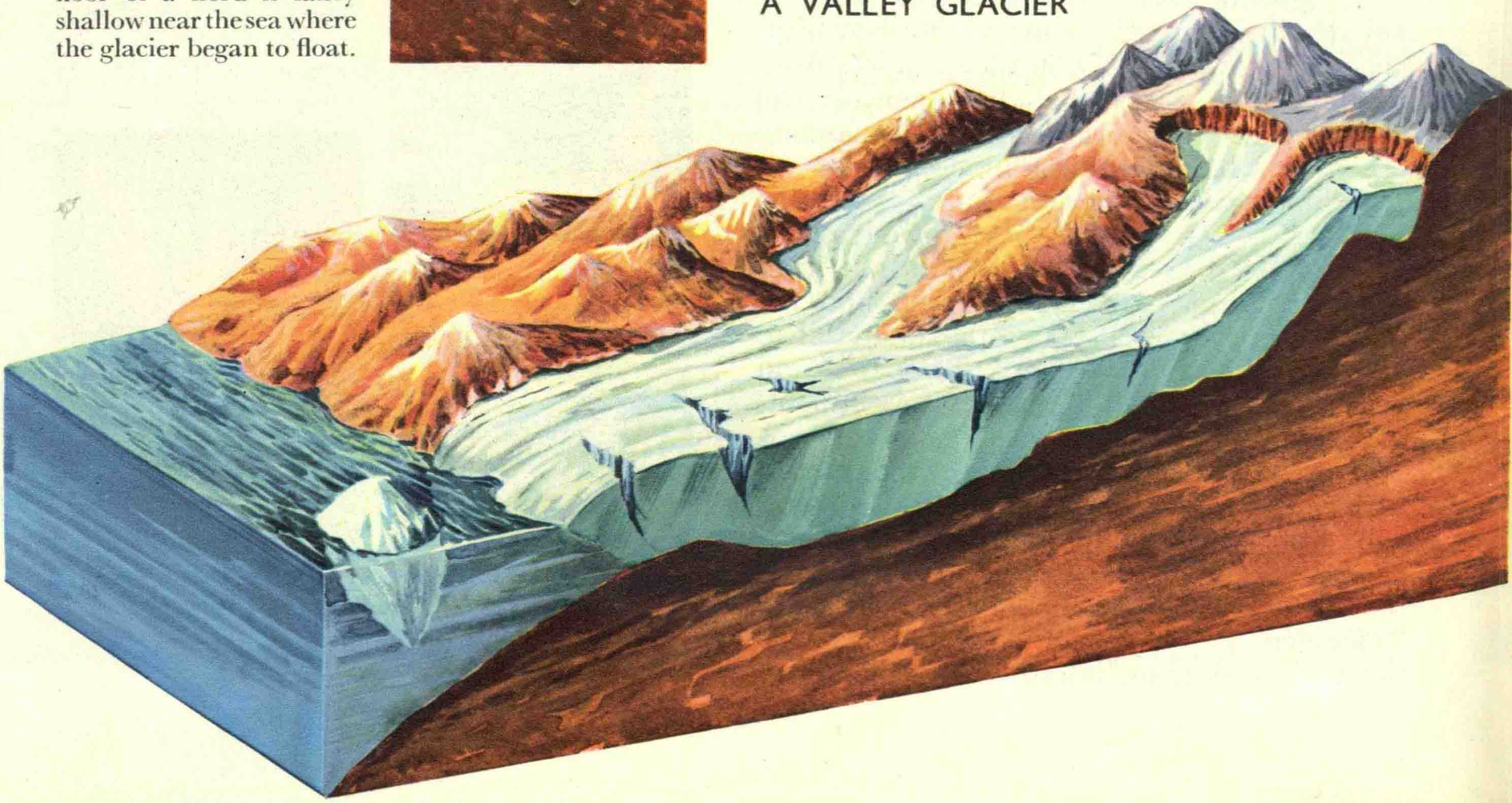
Frost can cause soil to *creep* down slopes. The pictures show how soil particles, having been lifted by frost, fall back lower down the slope when thawed.

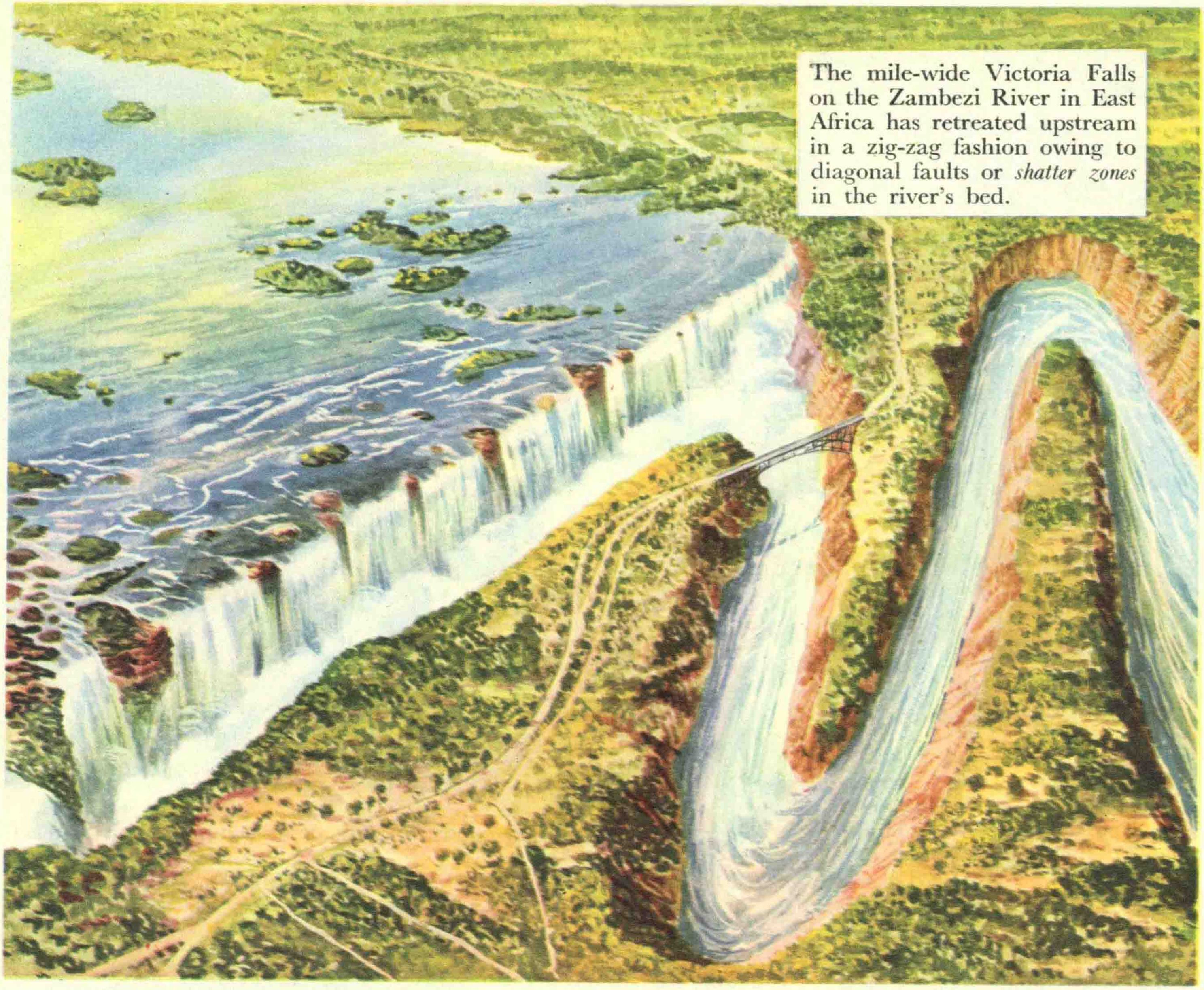
The picture opposite is a cross-section of a *fiord*, the valley that may be left when a glacier, such as the one shown in the diagram below, melts. The valley sides are sheer, bare rock walls, towering hundreds of feet above deep water. The valley floor of a fiord is fairly shallow near the sea where the glacier began to float.



A wind-sculptured rock

A VALLEY GLACIER



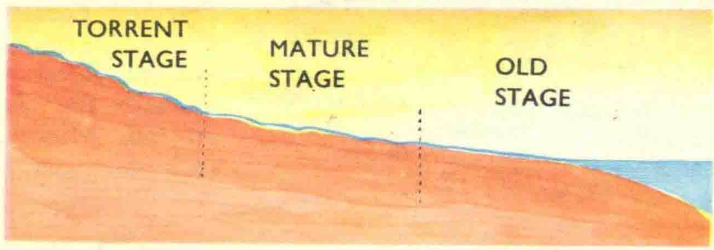


The mile-wide Victoria Falls on the Zambezi River in East Africa has retreated upstream in a zig-zag fashion owing to diagonal faults or *shatter zones* in the river's bed.

Rivers and Landscapes

A *youthful* landscape is an area of land which has only recently been uplifted (in geological time). This is the time when the tools of erosion are most destructive. The small young streams rush down steep slopes and over many waterfalls, their speed giving them great power to eat away the land.

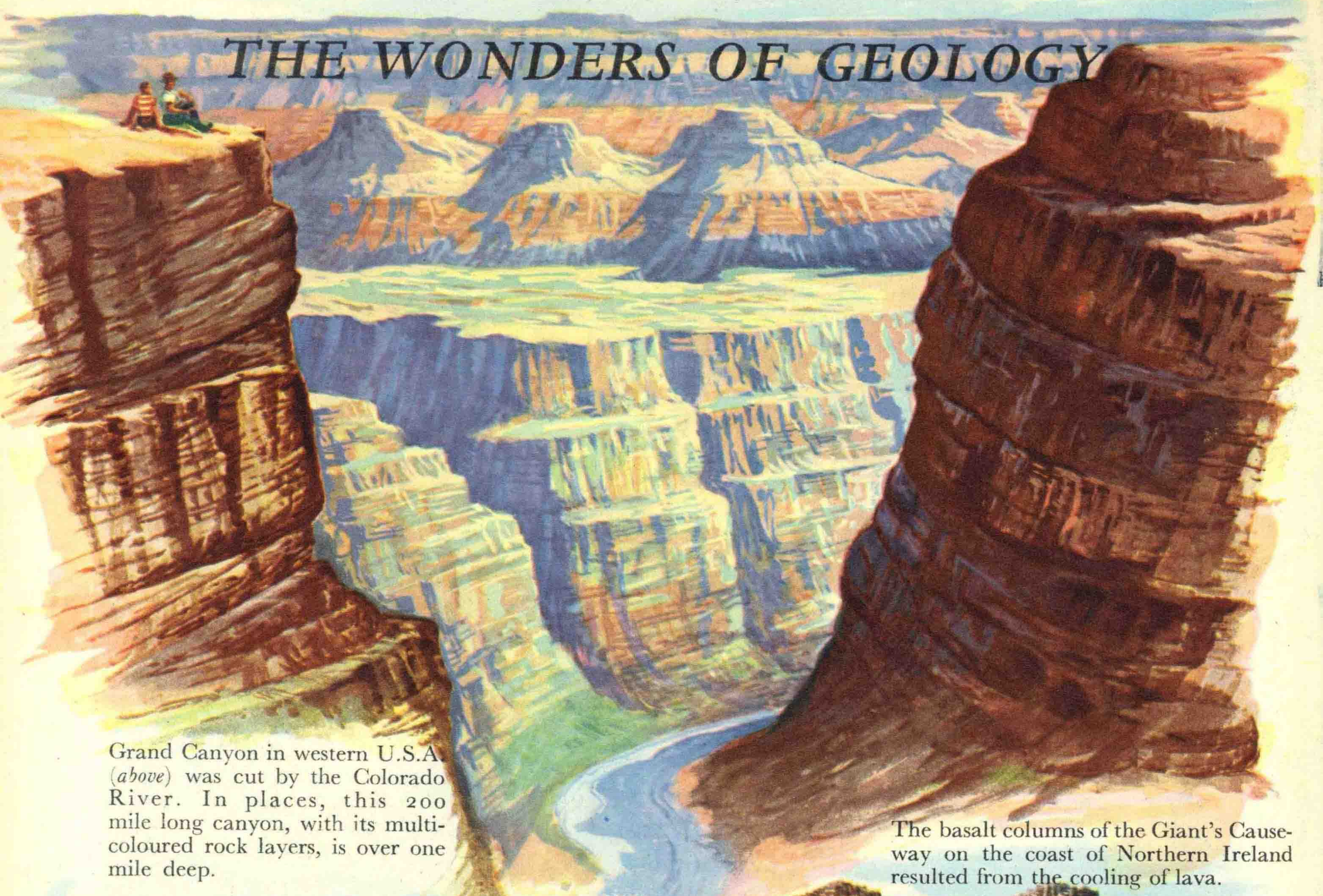
Gradually the craggy mountains are smoothed off and worn down by ice and water to produce a *mature* landscape, where the countryside is soft and rolling. By now the main rivers have carved themselves wide gently-sloping valleys. But as all steep slopes are smoothed away, the speed of the rivers decrease until finally, after many thousands of years, they flow lazily in great loops over a nearly flat plain.



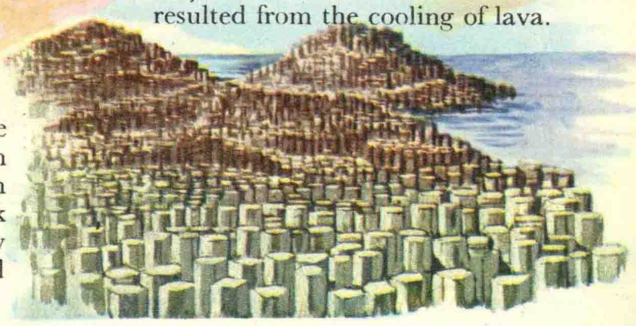
A large river is only wide and sluggish in its lower reaches, when it nears the sea. The headstream and highland tributaries may rush down steep slopes over waterfalls and through gorges. This is called the *torrent* stage. The *mature* section of a river is where the valley is broad and the slope gentle.

The rejuvenation of a stream (see glossary) leads to the formation of river terraces.

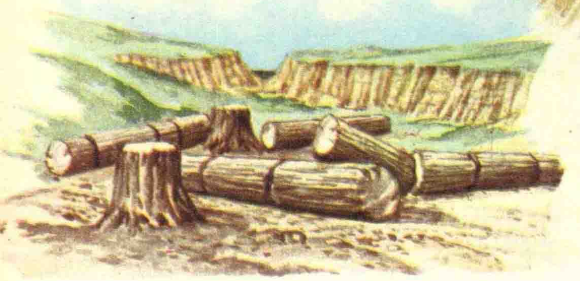
THE WONDERS OF GEOLOGY



Grand Canyon in western U.S.A. (*above*) was cut by the Colorado River. In places, this 200 mile long canyon, with its multi-coloured rock layers, is over one mile deep.



The basalt columns of the Giant's Causeway on the coast of Northern Ireland resulted from the cooling of lava.



The stone tree stumps of the Petrified Forest in western U.S.A. are the remains of an ancient forest which sank beneath the then swampy ground. Minerals produced rock casts. (see page 130).

Glossary

Arete The sharp edge on the col between two glacial valleys or corries.

Boulder Clay Stony clay deposited by glaciers.

Butte An isolated mass of hard rock left after softer rock around it has been worn away.

Canyon A steep-sided valley often formed where a river cuts down quickly through a rising land mass.

Col A pass in a mountain range where erosion has eaten back from both sides, so indenting the ridge.

Corrie A round, steep-sided basin in glaciated mountains which marks the head of a small glacier.

Cuesta A steep-fronted hill of dipping rock layers. The steep front *scarp* is backed by a gentle *dip slope*.

Dip and Strike The visible slope of tilted rock layers is known as *dip*. The *strike* is the line along which they cut the ground.

Drowned Valleys Submerged coastal valleys caused by a fall in land level.

Drumlins Egg-shaped mounds of boulder clay left by melting glaciers.

Fault A crack in once continuous rock layers due to stresses and strains in the earth's crust.

Folds Warps in rock layers due to great pressures in the earth's crust.

Levee A bank of sediment built above the general level of the river during floods.

Loess Dust or fine soil, sometimes from a desert, blown by wind over great distances.

Meanders The curves and loops of a mature river's winding course.

Morraines Sand and gravel ridges left by melting glaciers.

Ox Bow Lake An old river may cut across a pronounced loop in its course, leaving it as a lake.

Peneplain A low and level plain of erosion.

Plateau A high level area of uplifted land.

Rejuvenation A fall in sea level may cause a sluggish river to start cutting down through its old flood deposits, leaving *terraces* on either side.

Scree A skirt of rubble eroded from a rock face.

Watershed An area of high land, dividing at least two river systems.

INDEX

INDEX

A

B

C

D

E

F

G

H

I

J

K

L

M

N

O

P

Q

R

S

T

U

V

W

X

Y

Z

The artists whose work appears in this edition of THE ILLUSTRATED ENCYCLOPÆDIA OF SCIENCE are as follows: J. Cumming; Helen Haywood; Peter Jackson; A. Jessett; R. W. Jobson; C. J. Johnstone; J. Keay; J. Lewsley; G. O'Leary; B. W. Ovenden; E. H. Paul; B. Robinson; Edgar Sears; S. A. Smith; W. H. Wiggins.

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Reference Tables

It has been said that in Science nothing is certain until it can be measured. In this book the c.g.s. (centimetre-gram-second) system of measurement has been used, with occasional examples of the more familiar British f.p.s. (foot-pound-second) system. Once the units of length, mass and time have been established practically all other units may be derived from them.

Velocity=length/time ∴ its unit is the cm./sec.

Acceleration=velocity/time ∴ its unit is the cm./sec./sec.

Force=mass×acceleration ∴ its unit, the dyne, is the force required to give an acceleration of 1 cm./sec./sec. to a mass of 1 gm.

Work=force×distance ∴ its unit, the erg, is the work done when a force of 1 dyne is moved through 1 cm.

Energy is a body's capacity for doing work ∴ it has the same unit, the erg.

Power=work/time ∴ its unit is the erg/sec.

Area=length×length ∴ its unit is the cm^2 or sq. cm.

Volume=length×length×length ∴ its unit is the cm^3 or c.c. (cubic centimetre)

Pressure=force/area ∴ its unit is the dyne/sq. cm.

Density=mass/volume ∴ its unit is the gm./c.c.

The corresponding British units are given in the following table:

Quantity	Unit
Velocity	ft./sec.
Acceleration	ft./sec./sec.
Force	lb. wt.
Work and Energy	ft.lb. wt.
Power	ft.lb./sec.
Area	sq. ft.
Volume	cu. ft.
Pressure	lb./sq. in.
Density	lb./cu. in.

These absolute units are used in calculations. Some are not convenient for practical measurements.

SOME UNITS USED IN SCIENCE

1 ångstrom = 10^{-10} metre (length)
1 micron = 10^{-6} metre (length)
1 metre = 39·37 inches (length)
1 kilometre = 0·621 mile (length)
1 kilogram = 2·2 pounds (mass)
1 joule = 10^7 ergs (work)
1 horsepower = 550 foot-pounds per second (power)
1 calorie = 4·19 joules (heat energy)
1 electron volt = $1{\cdot}6 \times 10^{-12}$ ergs (energy)
1 watt = 1 joule per second (power)
1 kilowatt = 1·34 horsepower (power)
1 litre = 1000 cubic centimetres (volume)
1 light year = $9{\cdot}47 \times 10^{12}$ Km (distance)

INDICES

The notation of indices avoids having to write out long numbers.

Thus $1000 = 10 \times 10 \times 10$ becomes 10^3

$0{\cdot}001 = \frac{1}{1000}$ becomes 10^{-3}

PREFIXES

Deci- = a tenth = 10^{-1}
Centi- = a hundredth = 10^{-2}
Milli- = a thousandth = 10^{-3}
Micro = a millionth = 10^{-6}
Deca- = ten times = 10
Hecto- = a hundred times = 10^2
Kilo- = a thousand times = 10^3
Mega- = a million times = 10^6

GREEK SYMBOLS

Many of the symbols used in Science are taken from the Greek alphabet.

The lower-case letters are given below:

α	Alpha	ι	Iota	ϱ	Rho
β	Beta	$\varkappa$	Kappa	σ	Sigma
γ	Gamma	λ	Lambda	τ	Tau
δ	Delta	μ	Mu	υ	Upsilon
ε	Epsilon	ν	Nu	φ	Phi
ζ	Zeta	ξ	Xi	χ	Chi
η	Eta	o	Omicron	ψ	Psi
θ	Theta	π	Pi	ω	Omega

A Table of Historic Events in Science

B.C.

640 Greek astronomer Thales of Miletus born
582 Pythagoras born
335 Aristotle opens his school in Athens
300 Euclid teaches Geometry in Alexandria
250 Archimedes of Syracuse founds science of hydrostatics

A.D.

130 Birth of Claudius Galen, the most notable of ancient medical writers
750 Geber, Arabian alchemist, experiments in chemistry
1200 Oxford University founded
1450 Gutenberg invents printing
1519 Death of Leonardo da Vinci
1530 Paracelsus introduces chemistry into medicine
1543 Copernicus claims that earth moves round the sun
1576 Tycho Brahe begins precise observations in astronomy
1602 Galileo constructs a thermometer
1615 Circulation of blood discovered by William Harvey
1654 Guericke demonstrates the "Magdeburg hemispheres"
1660 Foundation of the Royal Society
1662 Boyle's Law formulated
1668 Newton working in Cambridge
1735 Linnaeus publishes his *Systema Naturae*
1750 Franklin shows the electrical nature of lightning
1760 Joseph Black discovers and measures latent heat
1765 James Watt invents external condenser for steam engines
1771 Oxygen discovered independently by Priestley and Scheele
1775 Lavoisier explains the process of burning
1789 Volta investigates the first electric currents
1798 Rumford demonstrates conversion of work into heat
1808 Dalton proposes his atomic theory of matter

A.D.

1808 Cuvier establishes the geological order of rocks
1811 Avogadro's Hypothesis formulated
1820 Ampère shows the magnetic effect of an electric current
1825 George Stephenson opens the first railway
1827 Ohm's Law published
1831 Faraday generates electricity by using a magnet
1843 Joule determines the mechanical equivalent of heat
1858 Darwin and Wallace jointly announce the theory of evolution
1865 Science of genetics founded by Mendel
1869 Periodic table of elements devised by Mendeléef
1873 Maxwell states his electromagnetic theory of light
1887 Crookes discovers the properties of cathode rays
1895 Röntgen discovers X-rays
1896 Becquerel discovers radioactivity
1898 The Curies isolate radium
1900 Planck enunciates the Quantum Theory
1903 Powered flight achieved by the Wright brothers
1905 Einstein makes the first announcement of his relativity theory
1907 Triode valve invented by Lee de Forest
1911 Rutherford proposes his nuclear model of the atom
1913 Bohr proposes his planetary model of the atom
1917 Artificial nuclear disintegration produced by Rutherford
1919 Wilson invents the cloud chamber
1924 Theory of wave mechanics proposed by Schrodinger and others
1932 Chadwick discovers the neutron
1942 First nuclear reactor constructed in the United States
1957 Artificial earth satellite Sputnik I launched

AGRICULTURAL SCIENCE

Apart from the main soil foods, healthy plants need small quantities of such elements as copper, manganese and cobalt. These are called trace elements. Large areas of pastureland in Australia and New Zealand have been improved by the spraying of these vital elements.

Many years ago, when several people owned strips of land in one large field, they had little chance to experiment with new methods. It was only in the late 18th century, when most land had been enclosed into separately owned fields and estates, that farmers tried to increase the fertility and yield of their land. Most of the agricultural improvers were the owners of large estates, like Lord Townshend, who experimented with the four year rotation of crops, and Robert Bakewell and Thomas Coke, who developed the scientific breeding of livestock.

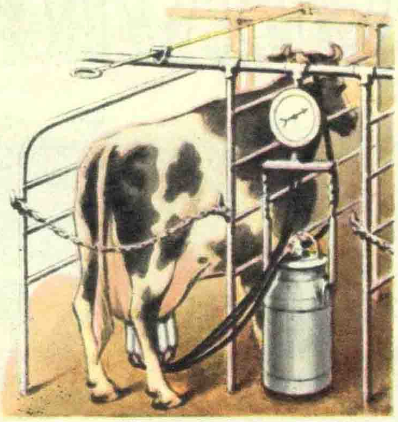
Since the 19th century, science has been employed in ever increasing degrees in the aid of farming.

Since earliest times farmers have realised that plants grow better in soil that has been coated with animal manure. But it was only in the middle of the 19th century when scientists discovered the elements present in plant food (mainly nitrogen, potassium, phosphorus and calcium) that they knew why. Artificial manures containing these important ingredients were manufactured soon after.

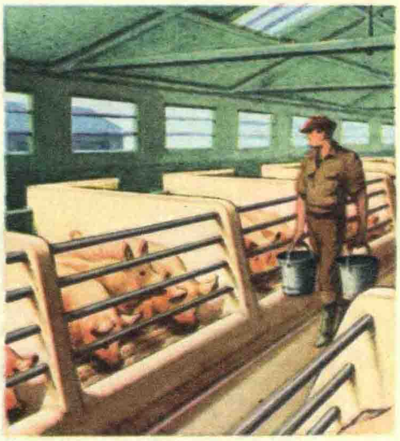
Ploughing in hilly areas may lead to soil erosion, the bare soil being washed away by rain water and streams. This danger is increased if the field is ploughed up and down the slope, for the furrows provide rainwater with ready-made channels. One way of avoiding erosion is to plough with the contours of the land (across the slope). The furrows then slow down the rush of rainwater.

Left. Biological control of plant pests. Ladybirds, which eat harmful insects, have been imported into Californian orange groves. *Right.* Chemical control. Potatoes may be sprayed to protect them from the Colorado beetle.

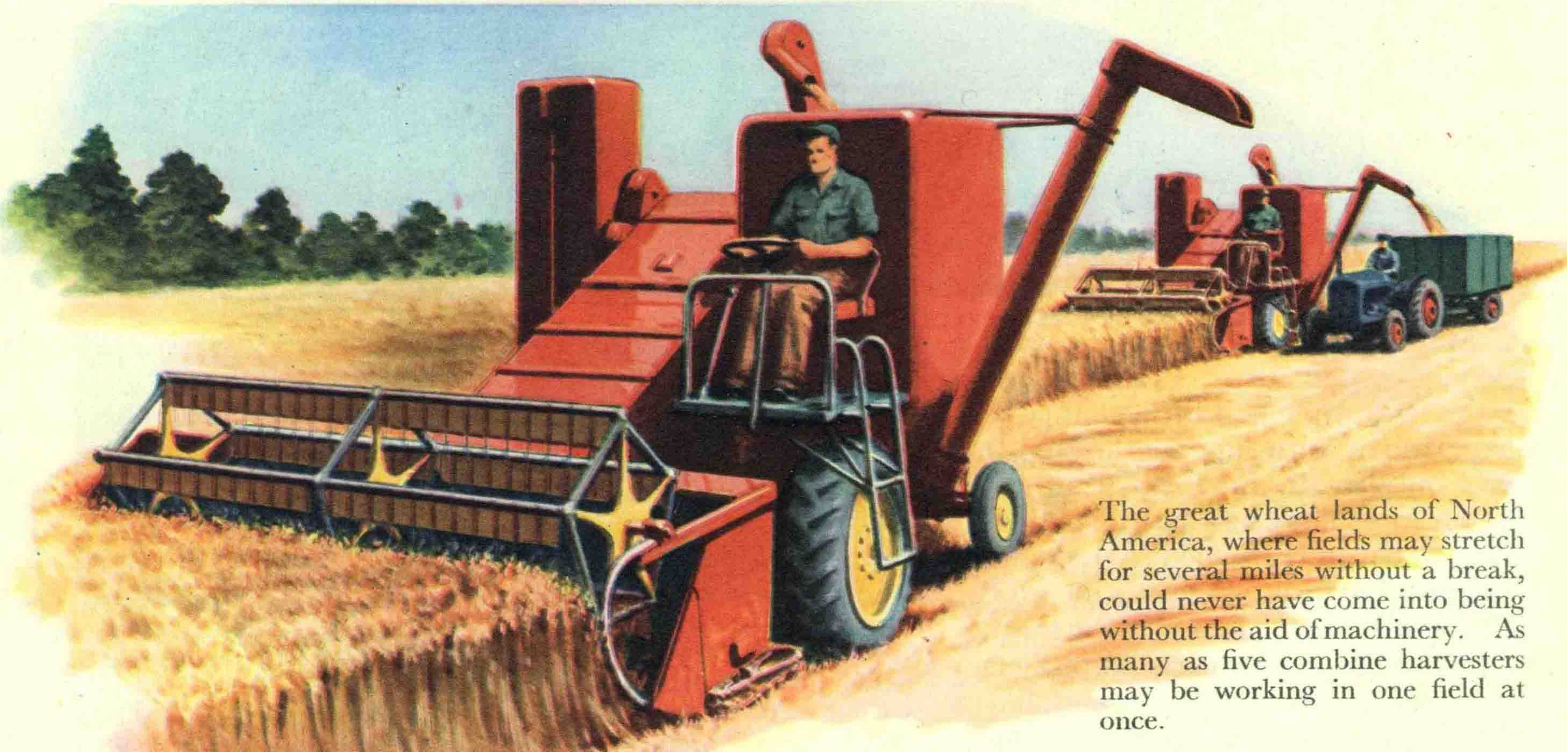
There were many more people living on farms in Europe and North America fifty years ago than there are today. But the crops are now much larger than they were then. This position has been brought about by improvements in farm machinery. Without machines, farmers would find it difficult to produce much more food than they actually needed for their own families. The great wheat lands of Canada and Australia, owe their existence to mechanised farming. Modern machines enable farmers to do their work more quickly and efficiently. They have also meant a decrease in the number of farm workers required.



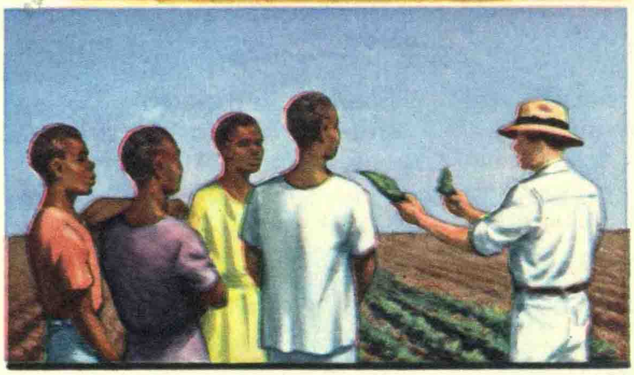
Milking machines, milk coolers, sterilizing equipment and cream separators are a great help to modern dairy farmers. Most cows take only 5 minutes to be milked by machine.



On some farms, particularly in Denmark, pigs are kept in indoor batteries and carefully fed until they reach the exact weight required for good quality pork and bacon.



The great wheat lands of North America, where fields may stretch for several miles without a break, could never have come into being without the aid of machinery. As many as five combine harvesters may be working in one field at once.

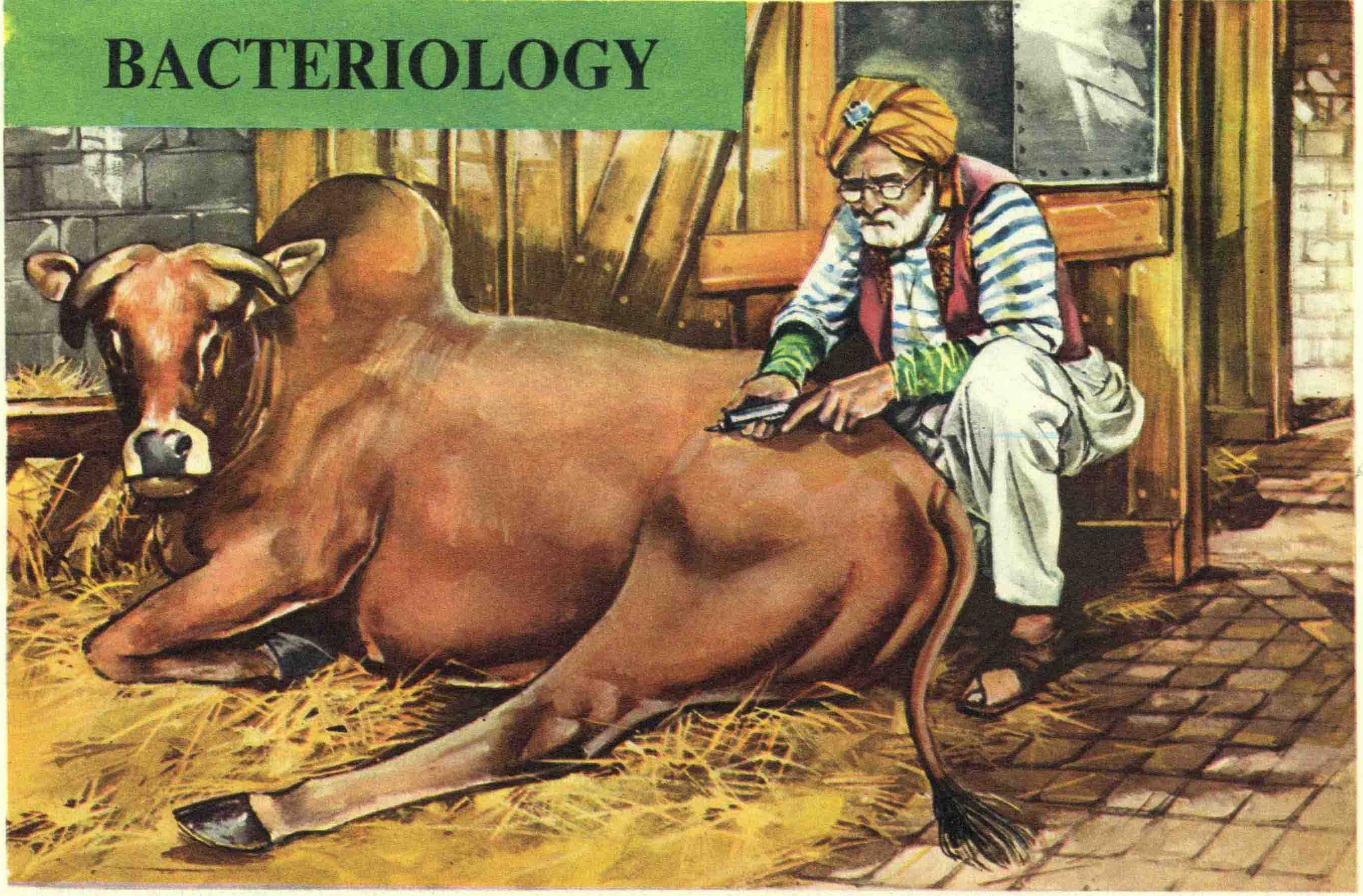


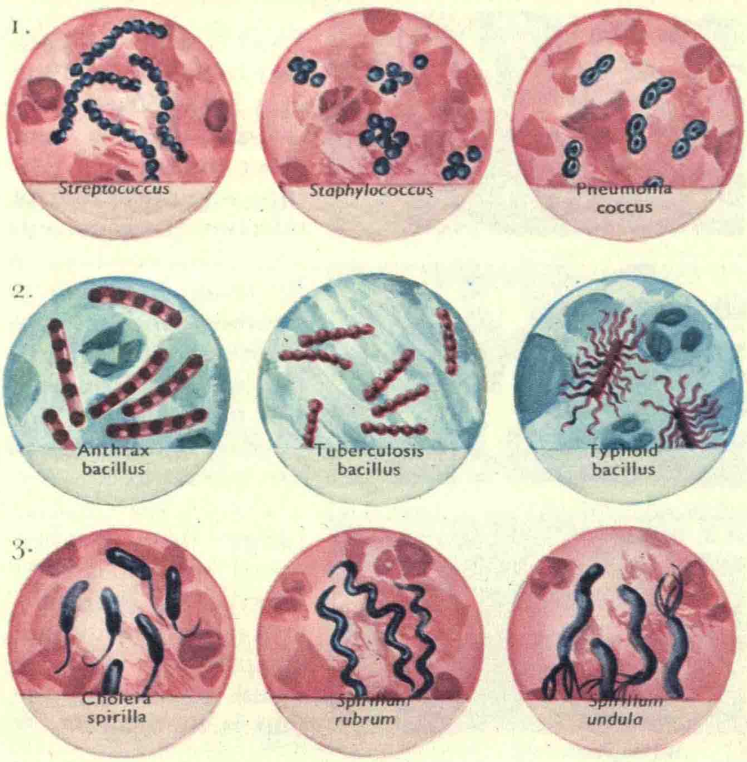
Community Development Centres have been established in many backward lands where the villagers are taught how to get the most out of their land by using modern farming methods.

Farmers have used simple machines for many thousands of years. Nobody knows, for instance, who invented the first plough. But agricultural machines changed very little through the centuries until the time of the Industrial Revolution.

In the 1800's many new farm machines (such as the reaper, seed drill and potato planter) were invented. Later in the same century, steam engines were used to pull and run some of the machines. But draught horses still had an important place in farming. The present century has seen powerful petrol and diesel tractors replace steam engines, and even horses, as the main source of power and locomotive force on farms.

BACTERIOLOGY



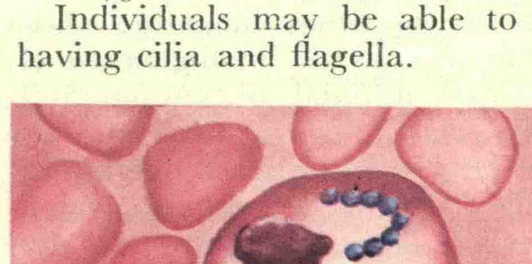


1. COCCI. 2. BACILLI. 3. SPIRILLI.
Though there are relatively few disease-causing bacteria, some of the diseases caused by bacteria can be fatal. At one time tuberculosis, smallpox, and diphtheria for example were nearly always fatal, but nowadays with the use of drugs, vaccination and other measures, deaths are comparatively rare.

Bacteriology is the study of bacteria, minute single celled organisms usually classified as plants. All higher animals ultimately depend for their existence on them. The majority of bacteria are useful, though it is, perhaps, the few disease-causing forms that directly affect us most.

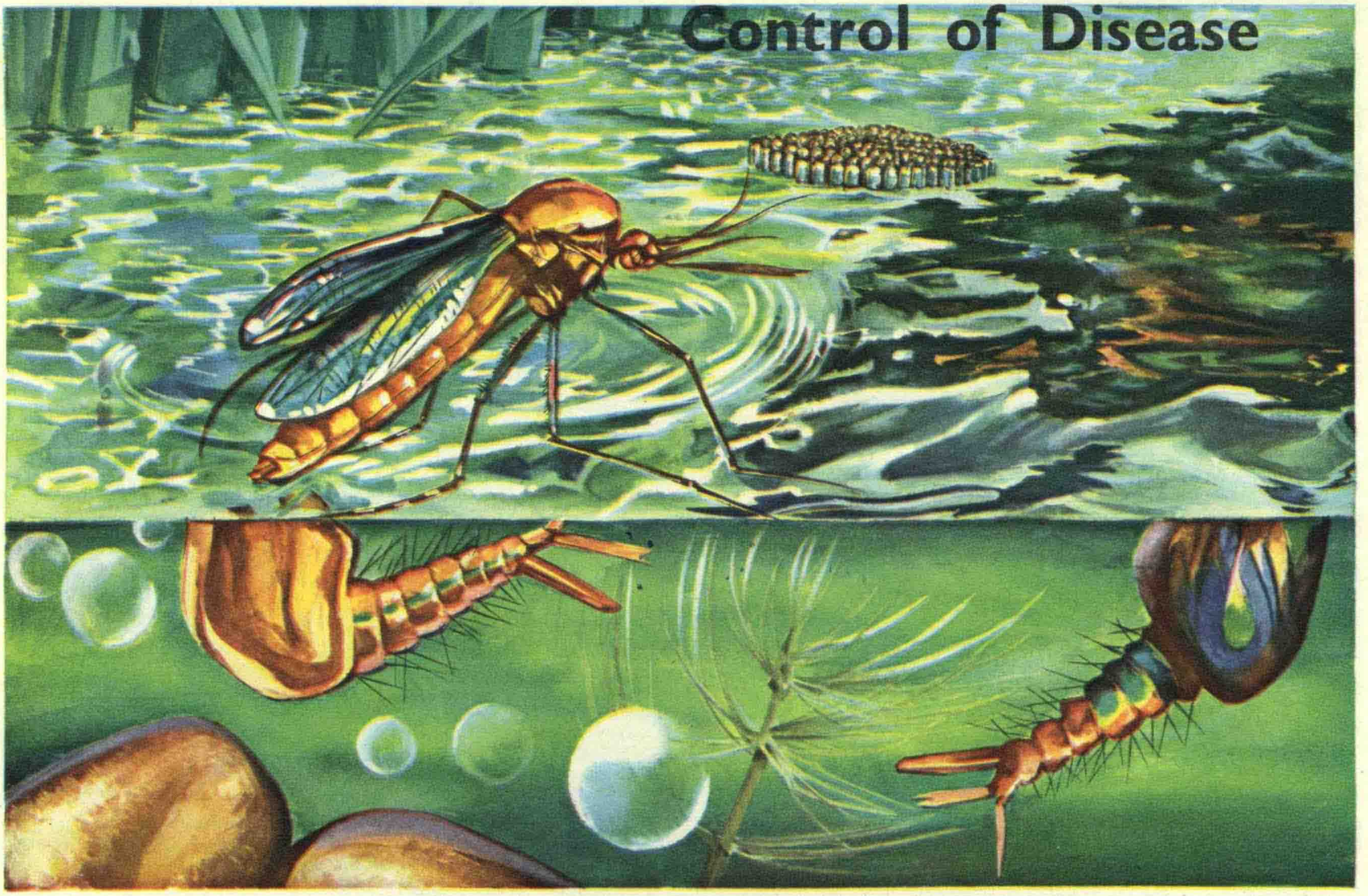
Apart from the viruses, some of which are closely related, bacteria are the smallest living organisms. Some are only one twenty five thousandth of an inch long. They occur in almost every situation, are not killed by cold, and some can withstand temperatures of over 75°C. in manure beds and hot springs.

Individuals may be able to move, some having cilia and flagella.



(Left) A phagocyte seen under the microscope with some bacteria, which it has engulfed, inside it. If a cut is infected by bacteria or other germs, phagocytes travel to the cut where they kill the bacteria.

Control of Disease

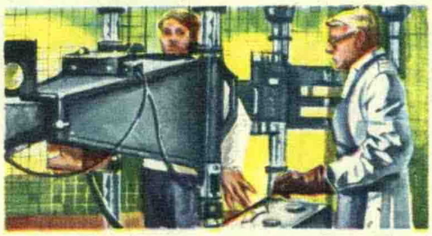


In the past, large areas of the world have been disease-ridden swamps, uninhabitable or near uninhabitable. Even inhabited areas have been badly affected by disease. To some extent this is still true, though today through our efforts in fighting disease, much of this land is lived on under more favourable conditions.

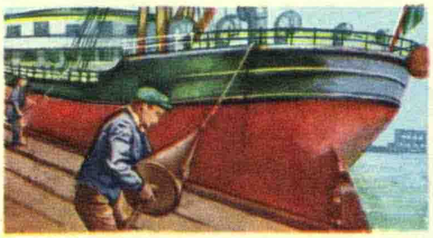
There are various ways in which we can control disease. Firstly, there are preventive measures which include vaccination, pasteurisation, sterilisation, the draining of swamps, and the spraying of insecticides. Secondly, there are curative methods—the injection of sera and the use of drugs including antibiotics. Thirdly there is the intelligent use of sanitation—proper disposal of sewage and other waste materials.

One of the largest anti-disease operations has been the fight against the mosquito, which carries the yellow fever organism. Many people have been employed draining the swampy breeding grounds. D.D.T. has been used in spraying every building inside and out in affected areas, in an attempt to kill the adult mosquitoes.

Food is sealed in cans and cooked for a time at a high temperature to kill bacteria and other organisms. In this way any risk of infection is removed.

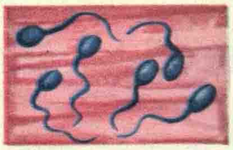


By using X-rays it is possible to diagnose a disease in its early stages. Cure is quicker and more likely. Because of X-rays there is less tuberculosis.

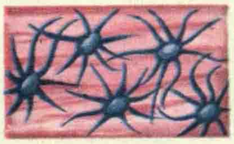


Large discs placed round the ropes used for tying up ships prevent rats from climbing aboard. If any are found on board the ship is fumigated.

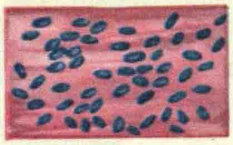
Nowadays, strict aseptic conditions are maintained in hospital operating theatres. Instruments are sterilised by boiling in water.



Nitrosomonas. A "nitrite bacterium," turns ammonium carbonate to a nitrite.



Bacillus radicicola. In root nodules. Fixes free nitrogen in air.

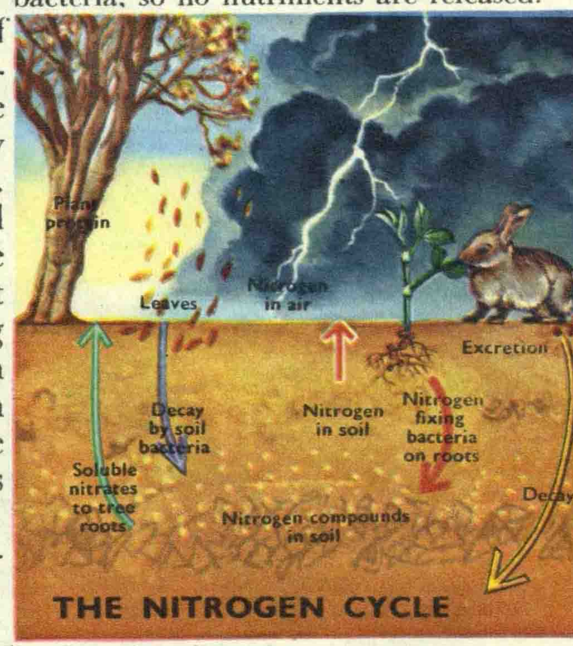


Nitrobacter. A nitrate bacterium which converts nitrites to nitrates.

Plants grown in soil deficient in manure and minerals have their growth affected. In the right hand pot manure has been added but the contents were sterilised, killing all the bacteria, so no nutriments are released.

In a teaspoonful of soil there are many thousands of millions of bacteria. Most are useful, and these are responsible for our supply of protein from the soil. They are concerned with the processes we term decay or rotting, by which nitrogen compounds are released for plant growtn. Through soil bacteria action, dead plants and animals and wastes are reduced to "humus". If this were not so the ground would become littered with animal and plant remains. No minerals would be regenerated for the living plants to absorb, and so all higher life would come to an end, as animals depend on plants, through lack of fresh material. Also in the soil are the root-nodule bacteria able to fix nitrogen from the air. These all contribute towards the nitrogen cycle.

Other useful bacteria are used commercially in fermentation processes (e.g. cheese and vinegar making).



Glossary

Aerobic bacteria must have free oxygen for respiratory purposes.

Anaerobic bacteria, unable to live in the presence of oxygen.

Antibiotics, substances made from living organisms which control or inhibit the growth of some harmful microorganisms, e.g., Penicillin, Streptomycin.

Antiseptic, chemical destroying or inhibiting growth of microorganisms, e.g., dettol.

Asepsis, the prevention of bacterial infections as used nowadays in all surgical operations. The surgeon and his assistants all wear sterile clothing, and instruments are sterilised by boiling.

Carbon cycle. Most elements circulate in nature (c.f. Nitrogen cycle). Bacteria take part in the carbon cycle. Carbon dioxide and water taken up by plants are built up into carbohydrates, including cellulose. Cellulose-bacteria break this down by means of a special enzyme (cellulase), into water, methane, and carbon dioxide.

Fermentation. Bacteria, like all living things, need energy to carry on their activities. If this energy is supplied by the destruction of the substrate on which they live, without oxidation, the process is termed fermentation.

Fumigation is a method of applying disinfectant, either by means of smoke, gas, or a very fine spray.

Humus. The remains of dead animals and plants in the soil (soil organic matter). The soil bacteria are constantly changing the humus. As it decays different substances are formed. Plants will be able to absorb some of these (e.g., nitrates). Humus is essential to productive soil. Besides supplying minerals it conserves moisture and loosens soil particles to admit air and water.

Inoculation. A virus inserted into a wound produces a mild form of a disease, causing antibodies to be formed in the blood. When the disease is actually encountered, the body has extra resistance besides its natural resistance.

Microbiology the study of microorganisms.

Microorganism literally a small living thing. It is a plant or an animal so small that it can only be studied under the microscope. Included under the name microorganism are bacteria, viruses, some algae, some fungi, and protozoa.

Pasteurisation. This is the method of preparing foods, particularly milk, to free them of disease-causing bacteria. Milk, for example, is heated to a temperature of about 150°F. for half an hour, following which it is cooled rapidly. The process is named after Pasteur. (Page 150).

Phagocyte is the name given to a type of white blood corpuscle (leucocyte) which is able to destroy harmful microorganisms by engulfing them in an amoeboid fashion (see page 251).

Root nodules small swellings on the roots of leguminous plants, e.g., clover (diagram above). Bacteria are found in the root nodules of a number of legumes. They have the ability of fixing the free nitrogen of the air. Thus in return for food they are able to give the plants valuable minerals such as nitrates which they themselves manufacture. This is an example of symbiosis (see Biology glossary).

Sterilisation the prolonged heating of something in order to kill all the bacteria. This is a much more severe process than pasteurisation since, in the case of food, much of the goodness is destroyed by heating for a long time. It may be effected by boiling in water, or heating with steam or hot air.

Vaccination (see Inoculation).

Vaccine prepared usually from weakened or killed organisms which cause a certain disease, or from the toxins of these organisms.

Virus the smallest living thing, so small that it can pass through the finest bacteria filters, and can only be seen under the electron microscope. Viruses are unable to exist outside the body of a living thing and so cannot be grown on culture media as can bacteria. Viruses cause many diseases. These include influenza, chicken pox, measles, mumps and poliomyelitis, in ourselves. Potatoes amongst plants are often affected by viruses.

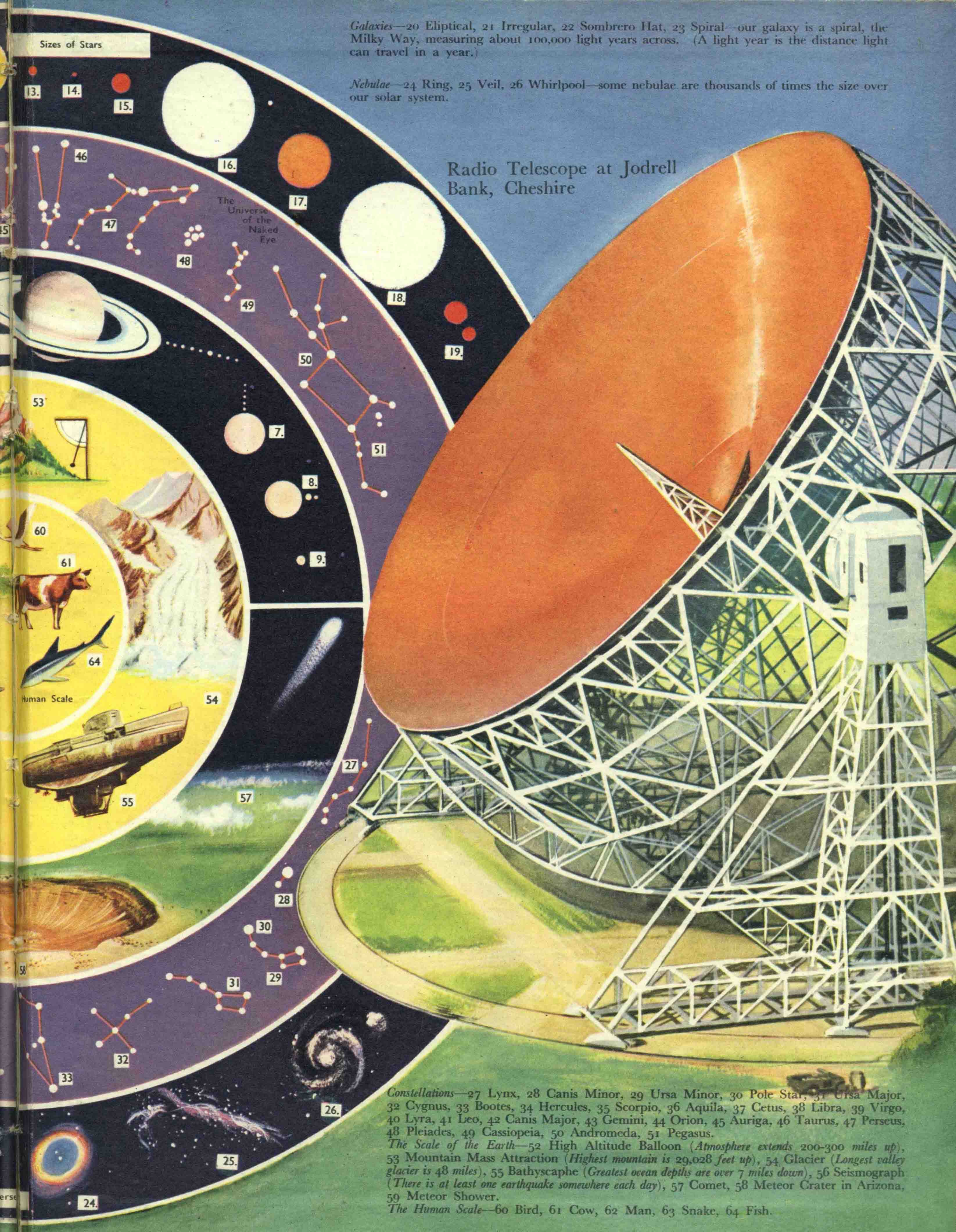
THE SCALE OF THE UNIVERSE

Planets—1 Mercury, 2 Venus, 3 Earth, 4 Mars, 5 Jupiter, 6 Saturn, 7 Uranus, 8 Neptune, 9 Pluto. Saturn, the largest planet, has a diameter of 88,700 miles; Pluto, the outermost is 3,670,000,000 miles from the sun.

Stars—10 Sun, 11 Proxima Centauri, 12 Centauri A and B, 13 Munich 15040, 14 Wolf 359, 15 Lalande 21185, 16 Sirius, 17 Ceti, 18 Procyon, 19 Kruger 60—Sun has a diameter of 864,000 miles; the largest stars are many times larger (*e.g.*, Alpha Herculis measures some 640,000,000 miles across).

Galaxies—20 Eliptical, 21 Irregular, 22 Sombrero Hat, 23 Spiral—our galaxy is a spiral, the Milky Way, measuring about 100,000 light years across. (A light year is the distance light can travel in a year.)

Nebulae—24 Ring, 25 Veil, 26 Whirlpool—some nebulae are thousands of times the size over our solar system.



Radio Telescope at Jodrell Bank, Cheshire

Constellations—27 Lynx, 28 Canis Minor, 29 Ursa Minor, 30 Pole Star, 31 Ursa Major, 32 Cygnus, 33 Bootes, 34 Hercules, 35 Scorpio, 36 Aquila, 37 Cetus, 38 Libra, 39 Virgo, 40 Lyra, 41 Leo, 42 Canis Major, 43 Gemini, 44 Orion, 45 Auriga, 46 Taurus, 47 Perseus, 48 Pleiades, 49 Cassiopeia, 50 Andromeda, 51 Pegasus.

The Scale of the Earth—52 High Altitude Balloon (*Atmosphere extends 200-300 miles up*), 53 Mountain Mass Attraction (*Highest mountain is 29,028 feet up*), 54 Glacier (*Longest valley glacier is 48 miles*), 55 Bathyscaphe (*Greatest ocean depths are over 7 miles down*), 56 Seismograph (*There is at least one earthquake somewhere each day*), 57 Comet, 58 Meteor Crater in Arizona, 59 Meteor Shower.

The Human Scale—60 Bird, 61 Cow, 62 Man, 63 Snake, 64 Fish.